THE ELEMENTS OF NAVIGATION

Photograph by Edwin Levick

LATEST TYPE SUBMARINE CHASER. SPEED, 30 MILES; HAS THREE 250-HP. ENGINES; MOUNTS 1-POUND RAPID-FIRE GUN FORWARD AND 6-POUNDER AFT

THE

Elements of Navigation

A short and complete explanation of the standard methods of finding the position of a ship at sea and the course to be steered

NEW AND ENLARGED EDITION

BY

illiam ames

W. J. HENDERSON, A.M.

FORMERLY LIEUTENANT IN THE FIRST BATTALION,
NAVAL MILITIA, OF NEW YORK

ILLUSTRATED

HARPER & BROTHERS PUBLISHERS
NEW YORK AND LONDON

BOOKS BY

W. J. HENDERSON

AFLOAT WITH THE FLAG
Illustrated. Post 8vo, Cloth,

SEA YARNS FOR BOYS, SPUN BY AN OLD SALT
Illustrated. Post 8vo, Cloth,

HARPER & BROTHERS, NEW YORK

ELEMENTS OF NAVIGATION

Printed in the United States of America
Published October, 1917

K-R

TO

COMMODORE ROBERT P. FORSHEW

COMMANDING THE NAVAL MILITIA

NEW YORK

CONTENTS

	PAGE
Preface to Latest Edition	ix
Publishers' Introduction	xi
Introduction	1
Variation	10
Deviation	13
How to Find the Deviation	18
Leeway	26
The Log	29
The Lead-line	35
Charts	37
Chart Sailing	44
Dead-reckoning	51
Examples for Practice	62
Working a Traverse	64
Hove To	68
Shaping the Course	69
Navigation by Observation	73
Adjustments	78
Index Error	80
Hints on Taking Altitudes	81
Correcting the Altitude	82
The Chronometer	86
The Nautical Almanac	89
Apparent and Mean Time—the Equation	95
Latitude by Meridian Altitude	97
Latitude by Meridian Altitude of a Star	105
Latitude by Meridian Altitude of a Planet	110
Latitude by Meridian Altitude of the Moon	111
Meridian Altitude Below the Pole	113
Use of Constant	116

	PAGE
Latitude by Ex-Meridian Altitude of the Sun	118
"Phi Prime" Sight	122
Latitude by the Polestar	126
Compass Error by Azimuths	138
Relations of Right Ascension and Hour-angle	139
Longitude by Chronometer (or Time) Sight	140
Remarks on Longitude	146
Longitude by Sunrise and Sunset Sights	148
Chronometer Sight of a Star	149
Sumner's Method	154
Example of Sumner's Method with the Sun	170
Example of Sumner Lines with Two Stars	174
St. Hilaire Method	179
Great-circle Sailing	184
Distance and Danger-angles	189
Allowance for Tides	195
Keeping the Log	197
Rating a Chronometer	199
Care of a Chronometer	204
The Navigator's Routine	207
Examples for Practice:	
Dead-reckoning	217
Shaping Course by Mercator's Sailing	218
Latitude by Meridian Altitude of Sun	218
Latitude by Meridian Altitude of Star	219
Latitude by Meridian Altitude Below the Pole	220
Latitude by Ex-Meridian Altitudes	220
Latitude by the Polestar	221
Longitude by Chronometer Sight	221
War-time Problems	223
The Naval Coast-defense Reserve	235

PREFACE TO LATEST EDITION

THE changes and additions in the present edition make this little volume a complete summary of the practice as now known. The principal illustrative problems have been brought up to dates in the year 1917, thus exhibiting the use of the present Nautical Almanac and the tables recently added to Bowditch's *Practical American Navigator.*

The latest navy method of marking compasses (from 1° to 360°), and of setting and correcting courses thereby, is fully treated.

The navy method of computing a constant for meridian sights is given.

The scope of utility for the –′ and –″ sight for latitude has been much enlarged by knowledge acquired since the first edition was written. The latest information and practice are now included.

The use of the moon has grown in favor and has been facilitated by a new table. The moon workings herein are brought up to date.

The new Nautical Almanac method of latitude by the Pole Star is treated fully.

The important Saint Hilaire method of

fixing a position on a Sumner line by the comparison of a computed and actual altitude is explained.

The latest form of navy log is given.

A chapter has been added covering the entire daily routine of the navigator's work from leaving his port of departure to entering his port of destination.

PUBLISHERS' INTRODUCTION

THE history of the three years 1914 to 1917 has been made with astounding rapidity and no part of it has been more absorbing than that dealing with naval operations. The position of our own country in the beginning of the great European war seemed to the casual observer to be one of perfect security. We had three thousand miles of ocean between us and the warring nations, and all we had to do was to mind our own business and nothing could happen to us.

But it slowly dawned upon all minds that unless we were disposed to mind our own business by withdrawing from the Atlantic Ocean and making no attempt to send our ships into European ports, we should presently be forced either to defend our rights or to admit that we did not have any.

The nature of the naval warfare developed by the skill and daring of the Germans—to take no account of the lawlessness of it—compelled England to invent novel and exciting measures of defense. The submarine

vessel was not new: all nations were acquainted with it. But it had been regarded as a weapon of offense against battle-ships and cruisers.

When Germany disclosed her policy of building these craft in large numbers and using them for the destruction of merchantmen, the world suddenly learned that a new type of commerce-destroyer had come into existence and that new methods of safeguarding the cargo-carriers must be devised. The British coasts are surrounded by a cordon of trawlers used in mine-sweeping and motor vessels designed and operated as submarine-chasers.

In the summer of 1916 the Germans sent to the United States a commercial submarine called the *Deutschland*. She made two voyages, once landing at Norfolk and once at New London. We are told that she was the avant-courier of a fleet of submarine cargo-carriers whose only purpose was to restore commercial intercourse with this country, made impossible for surface ships by the British blockade.

As the relations between the United States and Germany became more and more difficult because of the deaths of American citizens on peaceful merchantmen sunk by German sub-

marines, the German Government deemed it wise to give us a gentle hint of what might happen to us if we did not behave with the greatest discretion. Accordingly, U-boat 53, a war-vessel, suddenly arrived in Newport, and after a brief stay put to sea again, where she promptly sank several ships close aboard of our coast and forced us to send our naval craft to rescue the passengers and crews.

Before this naval officers had known well that it was our duty to prepare for trouble. But even this incident did not serve to arouse the people at large, and the beginning of our war with Germany found us struggling to develop overnight an adequate fleet of small patrol and guard vessels to protect our coasts and our shipping from the attacks of German sea raiders or the more dreaded submarine.

The Navy League contributed much to the spread of information on this vital subject and the newspapers published pictures of the type of motor-launches (as they are called) designed by Great Britain. These are vessels in the neighborhood of one hundred feet in length and of very light draught. They offer no target for torpedoes, and the submarine (not submerged) which meets one must depend on her shell fire.

Furthermore, these vessels are very quickly built, are very speedy, and can outmanœuver a submarine. The development of the marine motor in recent years has of course made these vessels a possibility and placed the handling of their machinery within the reach of all kinds of men. Here, then, is an opportunity for service awaiting every yachtsman and fisherman.

One officer and a very small crew, containing at least one expert gunner, is required for each boat. Since the work will be exceedingly rough, up and down the coast, close inshore, or well off in all kinds of weather, day and night, the officers will need to be navigators possessed of ready knowledge and resource.

This book, which was designed originally for the benefit of naval-militia officers and yachtsmen, ought to find a welcome among men who are preparing for the coast service. If for no other reason, the volume should be desirable because, while it is of most convenient size, it contains the whole science of practical navigation.

The book has stood the test of more than twenty years. It is more popular to-day than in its earliest seasons. When it was first published the Navy Department imme-

diately placed it on the list of works recommended for use by the naval militia and took a number of copies which were distributed among the various organizations in order to introduce it. Since that time the work has had continual favor among naval militiamen preparing for examinations as officers.

When the war with Spain began a large number of officers of the Navy who had resigned, but wished to volunteer, used this book as the most suitable for a quick and firm recovery of their knowledge of navigation. As one of them said to the author, "I could never have got back into the service if it had not been for your book."

Yachtsmen also have found this a convenient treatise for their purposes and many of them have testified as to its value.

Not a few master mariners, captains of vessels trading in foreign ports, have taken the book up and keep it in their cabins because of its compact presentation of all essential formulæ.

The work has thus had approval which has been extremely gratifying to the publishers and the author. The present time offers the widest field of usefulness for such a volume, and this new edition has been prepared to meet the conditions.

Additions covering the organization and manning of the Naval Coast Defense Reserve and subjects connected with navigation which should be known by its officers have been made. Hints about practical methods of coastwise navigation under war-time conditions, suggestions as to the study of coast sky-lines, the furthest development of the use of compass and lead in the blind work of unlighted nights or fogs, and the inestimable value of lines of bearing in sailing along a coast have been added by the author, who has sought to give them the directness, brevity, and completeness of the older portions of the book.

The publishers hope that in its new form this volume will prove of increased usefulness.

THE
ELEMENTS OF NAVIGATION

ELEMENTS OF NAVIGATION

THE reader of this book is cautioned that no words are wasted in it. Facts are stated once and not repeated. Explanations are given but once. The student must master each fact, each explanation, and each process before proceeding to the next.

A navigator's library should contain such works as the *American Coast Pilot*, Findlay's *North and South Atlantic*, and others of similar kind.

It is presumed that the student knows what latitude and longitude are, and that he can add, subtract, multiply, and divide degrees, minutes, and seconds, and hours, minutes, and seconds, and can work with decimal fractions.

Navigation is the art of finding the geographical location of a vessel at sea, the most direct course to be steered in pursuit of the voyage, and the distance to be made.

There are two branches of the art—dead-reckoning and observation.

Navigation by dead-reckoning consists in actually measuring the courses and distances sailed by the ship, and from them computing the distance and direction from the port left and to the port sought.

Navigation by observation consists in measuring the angular altitude of celestial bodies above the horizon, and computing the position of the ship by the application of astronomical and mathematical laws.

The problems of dead-reckoning are solved by plane trigonometry; those of observation by spherical trigonometry. But as the trigonometrical data are all provided in the tables printed in epitomes of navigation, the mariner is not required to be acquainted with any higher mathematics than simple arithmetic.

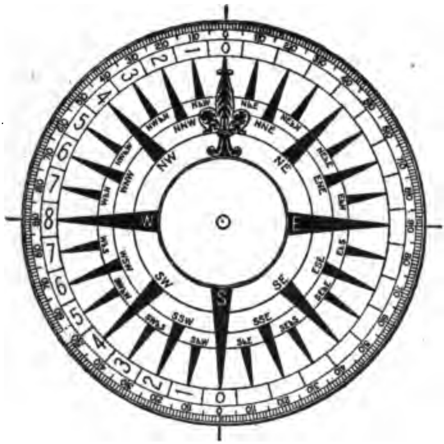
The instruments used in dead-reckoning are the compass, log, and lead-line. The compass shows the direction in which the ship is travelling; the log measures the speed or the distance. The lead is used when on soundings to measure the depth of water and ascertain the character of the bottom. These data, referred to the chart, throw valuable light on the question of the ship's position. Approaching a coast in

thick weather, or on a dark, cloudy night, the lead is the navigator's main reliance.

In addition to these instruments, the navigator requires for all his work accurate charts of the waters which he is traversing and their coasts. Charts issued by governments are more trustworthy than those published by private firms, which have not the resources of nations.

The mariner's compass is the first instrument which the navigator must know. It is presumed that any person who reads this book has seen a compass; therefore it is not described. The card is the part which concerns the learner at this point. Its circumference is divided into 32 equal parts, called points. Each point has a name; all these names the student must learn.

Any intelligent person can easily discover the system on which the points are named. North, south, east, and west are called the cardinal points; northeast, southeast, southwest, and northwest are the intercardinal points. Each cardinal point is 8 points away from the nearest cardinal, and 4 points away from the nearest intercardinal,



COMPASS-CARD, SHOWING POINTS AND DEGREES

All courses may be reckoned from the north-and-south line of the compass, which is called the meridian. Thus north-northeast, south-southeast, north-north-west, and south-southwest are 2-point courses. East and west are 8-point courses. Southeast-by-south is a 3-point course. The student should examine the compass card and see how many courses of each kind there are, bearing in mind that there

is nothing greater than an 8-point course. After a careful study of the points the student should be able to answer with facility all such questions as these:

How many 1-point courses are there? 2-point? 3-point, etc.? Name them. How many points is it from E.S.E. to S.W.-by-S.? How many points from N.E.-by-E. to W.-by-S.? How many points from E.-by-S. to E.N.E.? What points are 3 points away from W.-by-N.?

Again, a square-rigged vessel beating to windward will sail a course 6 points off the wind. The navigator must be able to answer all such questions as these: Heading N.N.E. on the port tack, how will the vessel head when she has come about? (The answer will require a count of 12 points.) Ship heading S.-by-W. close hauled on the starboard tack, what direction is the wind?

Until the student is master of the points of the compass and their relations he should go no further. When he has learned them, he must acquaint himself with the half and quarter points as set forth in the following table.

The next step is to learn the angle which

each course makes with the meridian. Meridians are imaginary lines running north and south from pole to pole and used for the determination of longitude.

TABLES SHOWING THE NAMES OF POINTS AND QUARTER-EACH COURSE, AND THE ANGLE MADE BY EACH WITH

North		Points	
N.¼E.	N.¼W.	¼	2° 48′ 45″
N.½E.	N.½W.	½	5° 37′ 30″
N.¾E.	N.¾W.	¾	8° 26′ 15″
N.-by-E.	N.-by-W.	1	11° 15′ —
N.-by-E.¼E.	N.-by-W.¼W.	1¼	14° 3′ 45″
N.-by-E.½E.	N.-by-W.½W.	1½	16° 52′ 30″
N.-by-E.¾E.	N.-by-W.¾W.	1¾	19° 41′ 15″
N.N.E.	N.N.W.	2	22° 30′ —
N.N.E.¼E.	N.N.W.¼W.	2¼	25° 18′ 45″
N.N.E.½E.	N.N.W.½W.	2½	28° 7′ 30″
N.N.E.¾E.	N.N.W.¾W.	2¾	30° 56′ 15″
N.E.-by-N.	N.W.-by-N.	3	33° 45′ —
N.E.¾N.	N.W.¾N.	3¼	36° 33′ 45″
N.E.½N.	N.W.½N.	3½	39° 22′ 30″
N.E.¼N.	N.W.¼N.	3¾	42° 11′ 15″
N.E.	N.W.	4	45° — —
N.E.¼E.	N.W.¼W.	4¼	47° 48′ 45″
N.E.½E.	N.W.½W.	4½	50° 37′ 30″
N.E.¾E.	N.W.¾W.	4¾	53° 26′ 15″
N.E.-by-E.	N.W.-by-W.	5	56° 15′ —
N.E.-by-E.¼E.	N.W.-by-W.¼W.	5¼	59° 3′ 45″
N.E.-by-E.½E.	N.W.-by-W.½W.	5½	61° 52′ 30″
N.E.-by-E.¾E.	N.W.-by-W.¾W.	5¾	64° 41′ 15″
E.N.E.	W.N.W.	6	67° 30′ —
E.N.E.¼E.	W.N.W.¼W.	6¼	70° 18′ 45″
E.N.E.½E.	W.N.W.½W.	6½	73° 7′ 30″
E.N.E.¾E.	W.N.W.¾W.	6¾	75° 56′ 15″
E.-by-N.	W.-by-N.	7	78° 45′ —
E.¾N.	W.¾N.	7¼	81° 33′ 45″
E.½N.	W.½N.	7½	84° 22′ 30″
E.¼N.	W.¼N.	7¾	87° 11′ 15″
East.	West.	8	90° — —

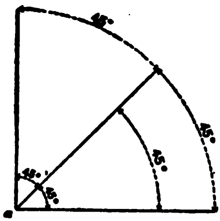
The meridian of the compass is so called because it is the north-and-south line, and may be regarded as coinciding with the imaginary meridian on which the ship is

POINTS, NUMBER OF POINTS AND FRACTIONS OF POINTS IN THE MERIDIAN.

South		Points	
S.¼E.	S.¼W.	¼	2° 48′ 45″
S.½E.	S.½W.	½	5° 37′ 30″
S.¾E.	S.¾W.	¾	8° 26′ 15″
S.-by-E.	S.-by-W.	1	11° 15′ —
S.-by-E.¼E.	S.-by-W.¼W.	1¼	14° 3′ 45″
S.-by-E.½E.	S.-by-W.½W.	1½	16° 52′ 30″
S.-by-E.¾E.	S.-by-W.¾W.	1¾	19° 41′ 15″
S.S.E.	S.S.W.	2	22° 30′ —
S.S.E.¼E.	S.S.W.¼W.	2¼	25° 18′ 45″
S.S.E.½E.	S.S.W.½W.	2½	28° 7′ 30″
S.S.E.¾E.	S.S.W.¾W.	2¾	30° 56′ 15″
S.E.-by-S.	S.W.-by-S.	3	33° 45′ —
S.E.¾S.	S.W.¾S.	3¼	36° 33′ 45″
S.E.½S.	S.W.½S.	3½	39° 22′ 30″
S.E.¼S.	S.W.¼S.	3¾	42° 11′ 15″
S.E.	S.W.	4	45° — —
S.E.¼E.	S.W.¼W.	4¼	47° 48′ 45″
S.E.½E.	S.W.½W.	4½	50° 37′ 30″
S.E.¾E.	S.W.¾W.	4¾	53° 26′ 15″
S.E.-by-E.	S.W.-by-W.	5	56° 15′ —
S.E.-by-E.¼E.	S.W.-by-W.¼W.	5¼	59° 3′ 45″
S.E.-by-E.½E.	S.W.-by-W.½W.	5½	61° 52′ 30″
S.E.-by-E.¾E.	S.W.-by-W.¾W.	5¾	64° 41′ 15″
E.S.E.	W.S.W.	6	67° 30′ —
E.S.E.¼E.	W.S.W.¼W.	6¼	70° 18′ 45″
E.S.E.½E.	W.S.W.½W.	6½	73° 7′ 30″
E.S.E.¾E.	W.S.W.¾W.	6¾	75° 56′ 15″
E.-by-S.	W.-by-S.	7	78° 45′ —
E.¾S.	W.¾S.	7¼	81° 33′ 45″
E.½S.	W.½S.	7½	84° 22′ 30″
E.¼S.	W.¼S.	7¾	87° 11′ 15″
East.	West.	8	90° — —

located. If an actual north-and-south line were ruled on the surface of the sea, and you started your ship off to the northeast, you would at once see that she was sailing on a course that made an angle of 45° from the meridian. But your compass will tell you the same thing.

The circumferences of all circles, no matter how large or how small, are divided into 360 equal parts called degrees, and all angles are measured by these. A single glance at the accompanying diagram will illustrate this. The angles at *a* do not increase in size because their boundary lines are prolonged. If these lines were prolonged till they reached the apparent sky the angle at their juncture would be the same size—45°. A degree, therefore, is $\frac{1}{360}$ of the circumference of any circle, no matter what size. Do not forget this important fact. If you divide the 360° of the compass-card by its 32 points, you will learn that 1 point equals 11° 15′. By add-



QUARTER-CIRCLE

ing 11° 15′ for each additional point, you will learn that 2 points equal 22° 30′, 3 points 33° 45′, 4 points 45°, 5 points 56° 15′, 6 points 67° 30′, 7 points 78° 45′, and 8 points 90°. Sailing-vessels cannot be steered closer than a quarter of a point, and for their navigation a quarter-point may be roughly estimated as 3°. Steamers can be steered more closely, and their courses are set in degrees. A course of this kind is expressed as so many degrees east or west from the meridian, thus: N. 47° E., S. 36° W. The latest method, however, is to express courses in degrees from 1° to 360°, as explained on p. 22. The student must master both methods.

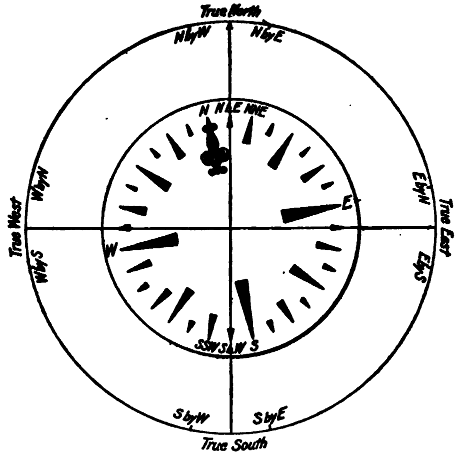
The north point of the compass indicates true or geographical north at only a few places on the globe. At all other places it points a little to one side or the other of north. This error is called variation of the compass.

It is caused by the fact that the magnetic north and south poles of the earth do not coincide with the true or geographical poles. The former is several hundred miles south of the geographical pole, and the latter several hundred miles north. The needle is perfectly true; it points right at the magnetic north pole. But that pole is not the north end of the earth's axis.

In navigating a vessel it is necessary to make allowance for this variation. The amount of allowance and its direction are indicated on the charts. On large charts, such as that of the North Atlantic, will be found irregular lines running from the top to the bottom of the paper, and having beside them such inscriptions as 10° W., 15° W. This means that along this line the variation of the compass from true north is 10° W., 15° W. There are certain lines

which have no variation, and here no allowance is to be made. On small charts, such as that of New York Bay, the variation is shown by the compass-card printed on the chart. The north point of it will be found slewed a little to the eastward or westward of a meridian line, and near it will be seen an inscription, such as "Variation 11° W. in 1892." Now let us see how this variation affects the compass aboard ship, and how we are to allow for it, so that we shall know exactly which way we are going, even when the compass does not tell the truth.

Let the outer circle represent the sea horizon, the inner circle the compass-card. The variation is one point westerly. Hence the north point of the compass points to the north-by-west point of the horizon, and the south point of the compass to the south-by-east point of the horizon. In other words, standing at the centre and looking towards the circumference, you find that every point on the compass is one point to the left of the proper place. If your compass says you are sailing north, you are really sailing N.-by-W. If it says south, you are going S.-by-E. If it says



VARIATION OF COMPASS

east, you are going E.-by-N. Hence we get these rules:

To correct a compass course.—When the variation is westerly, the true course will be as many points to the *left* of the compass course as there are points of variation. When the variation is easterly, the true course will be as many points to the *right* of the compass course.

Conversely, having ascertained the true

course between two places, you must construct the proper compass course by applying the variation, and the rule, therefore, is .

To convert a true course into a compass course.—Variation westerly, compass course to the *right* of true course; variation easterly, compass course to the left.

To illustrate for yourself, draw a large circle and mark off the compass points on it. Now cut out of stiff paper a miniature compass-card with the points marked. Fasten it by a pin through its centre to the centre of your large circle. By turning the north point of the compass-card as many points to the right or left of the fixed or true north as you have variation east or west, you will see at once how each separate point on the compass is affected.

DEVIATION

In addition to the magnetism of the earth, which affects all compasses alike, no matter how situated, we have to contend with deviation, which is a local error caused by the influence of neighboring iron or

steel. In ships built of either of these metals this influence is very great, and no compass aboard such a ship is ever quite correct, except possibly on one or two courses. As the compass-card does not turn with the ship when her course is altered, it follows that the mass of metal of which she is composed assumes new relations to the needles of the compass, and that, as a result, the error caused by deviation must change whenever the course is changed.

This is what makes the problems arising from deviation extremely troublesome, and it makes it necessary to ascertain the amount of error on each course. It is customary in modern vessels to use what are called compensated compasses. Before leaving port an expert, called a compass adjuster, ascertains the amount and direction of the deviation of each compass on the principal courses, and endeavors, by placing magnets in the deck, to counteract it. A certain amount of error always remains. This is noted by the adjuster, who will furnish the master of the ship with a table of residual errors, showing the amount and direction of the devi-

ation remaining on each course after adjustment.

Do not place great faith in these tables, for deviation changes in different conditions, and the residual errors will be altered.

It is not possible to treat the subject of deviation exhaustively in an elementary work of this kind. The student will be shown how to ascertain his deviation on each course and to make the necessary corrections. This is the only trustworthy method of dealing with this difficulty of navigation, and for the purposes of simple practice it is all that the beginner needs to know.

But no man is fit to take entire charge of the navigation of any vessel who does not know all about the nature and causes of errors of the compass. Therefore the student who aspires to mastery of the art of navigating should read Chap. II., Part I., and Chap. XII., Part II., of Lecky's *Wrinkles in Practical Navigation*, Evans's *Elementary Manual for Deviation of the Compass*, Towson's *Deviation of the Compass*, and Chap. III., Bowditch.

Some important cautions may be given

here. Keep all iron and steel as far from your compasses as possible.

Bear in mind that magnetic influence will not be stopped by placing anything between the compass and the iron or steel. It will pass through a stone wall.

If you use compensated compasses, see that the magnets, once placed by the adjusters, are let severely alone. They should never be touched.

Make it an invariable rule to ascertain the deviation of the compass on every course steered by the methods hereinafter explained, and to correct the course accordingly.

Bear in mind when ascertaining your deviation that it is good only for that one course. If your ship is heading E.S.E. and you find the deviation to be 10° E., it will be something else the moment you alter the course to E.-by-S., or even E.S.E.½E.

Bear in mind in taking bearings to apply the deviation according to the direction of the ship's head. For instance, you are lying at anchor. Your compasses have just been adjusted. The ship's head points N.W.-by-N. The table of errors says that on that course the deviation is one point

easterly. Directly on your starboard beam is a light-house. You wish to get its bearing. The compass says it bears N.E.-by-E. But you have one point easterly deviation. Hence the correct compass bearing is E.N.E.

The corrections for deviation are applied in exactly the same way as those for variation. Use the same rules.

Large vessels carry more than one compass. One of these is situated above the deck and as far away from local influences as possible. It is called the standard compass, and the ship is navigated by it.

To set a course by a standard compass.—Stand by the standard yourself and station a man at the steering compass. Order the helm to port or starboard till the ship is precisely on her course by the standard. At that instant blow a whistle (or give any other preconcerted signal), and the man at the steering compass notes the direction of the ship's head according to it. The course which he gets is the one to be given to the helmsman.

HOW TO FIND THE DEVIATION

In port. — Take the standard compass ashore, and set it up in a spot which is precisely in line between the regular station of the compass aboard ship and some distant object visible from said station. The bearing of the distant object by the standard compass will now be the correct compass (or magnetic, as it is usually called) bearing, unless you have been stupid enough to set up your compass near iron or steel.

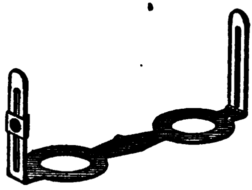
Now take the compass back aboard ship and set it up in its regular place. The ship must now be swung around so as to bring her head successively on each of the 32 points of the compass. At each heading take the bearing of the distant object before selected. The differences between the bearing obtained ashore and those now obtained will be the deviations for the successive headings of the ship. Your results should be tabulated thus:

Magnetic bearing	Course	Compass bearing	Deviation
S. 42° W.	N.	S. 43° W.	1° W.
S. 42° W.	N.-by-E.	S. 40° W.	2° E.
S. 42° W.	N.N.E.	S. 49° W.	7° W.
S. 42° W.	N.E.-by-N.	S. 38° W.	4° E.

And so on to N.-by-W. Your deviations, of course, will not vary thus from east to west. These figures are used simply to give practice in the application of the rules for the correction of deviation and variation. If the compass bearing is to the right of the correct magnetic bearing the deviation is easterly, and if to the left, westerly.

By the sun. — Some compasses are provided with a shadow pin, which sets up in the centre of the instrument. The sun casts a shadow of this pin, which falls on the card at the bearing opposite to that of the sun. Thus, if the shadow falls S.S.W., the sun bears N.N.E. You can thus get the compass bearing of the sun.

A better arrangement is the azimuth attachment. This is an arm with an upright at each extremity. It is arranged so that these uprights are directly opposite one another outside the circumference of the compass. Each upright is slit down the centre. In one is stretched a perpendicular hair, while the other is fitted with an eye-piece and a colored shade to deaden the rays of the sun. By sighting through the eye-piece and the hair one can get an



AZIMUTH ATTACHMENT

accurate bearing of the sun or any other object.

The instrument used most, however, and always in the Navy, is the azimuth circle. This fits firmly upon the compass bowl and has a mirror which throws a beam of light upon the card at the point indicating the bearing.

Having obtained the *compass* bearing, you consult Burdwood's or Davis's azimuth tables, which give the *true* bearing of the sun for every four minutes in the day. Burdwood's is for latitudes from 60° to 30°, and Davis's thence to the equator. A complete and admirably arranged set of azimuth tables, published by the Hydrographic Office, is used in the Navy. Take a compass bearing of the sun and note the time. Ascertain from azimuth tables the true bearing. The difference between this and your compass bearing will be the total error of the compass, embracing both variation and deviation. The chart gives the

variation. Take it from the total error and you have the deviation left.

EXAMPLE

Sun's true bearing at 3.15 P.M. ...... N. 150° W=S.	30° W.
Variation by chart	10° W.
Correct compass (magnetic) bearing	S. 40° W.
Bearing by ship's compass	S. 27° W.
Deviation	13° E.

You may ask why it is not sufficient to know the total error of the compass without ascertaining the deviation. The answer is that you may hold one course till you have changed your variation. If you do not know the deviation, you must now take another azimuth.

Another method of using the sun is by amplitudes, observed at rising or setting. The true bearings are given in Table 39, Bowditch. In using this, as well as Burdwood or Davis, you must know the latitude of your ship and the declination of the sun, which is obtained from the nautical almanac for the day. The peculiarity of the table of amplitudes is that it gives the bearings as so many degrees N. or S. of E. and W. Thus with latitude 15° N., declination 6° N., you get from the table an amplitude of 6.2, which at sunset would be

read W. 6° 12′ N., the true bearing of the sun.

Any other heavenly body whose declination is not greater than the range given in either the azimuth or amplitude tables can be used exactly as the sun is. A method of finding the true bearing of any celestial body, no matter how great its declination, will be given the proper place.

The U. S. Navy now uses compasses which have the degrees marked from 1° to 360°. The old system of marking from the meridian to east and west in quadrants of 90° each, as already described, has been abandoned. Hence, courses such as N. 71° E. or S. 45° W. are no longer given. The courses are all reckoned by the total number of degrees counting from North around by South and West, back to North. No geographical direction has to be expressed in such courses. The two just quoted would be named simply 71° and 225°. East becomes simply 90°; South, 180°; and West, 270°. Table 2 in new edition of Bowditch has the degrees marked for the newly named courses.

The student who expects to serve in the Navy or Naval Militia or on up-to-date

merchant steamers should be prepared to set or steer courses such as 165°, 237°, 368°, 379°.

The correction of such courses is extremely easy. The formula for correcting a compass course for variation and deviation is:

$$T.C. = C.C. + Var. + Dev.$$

All easterly variations or deviations have a plus sign prefixed; westerly, a minus sign. In other words, easterly error is invariably added to the number of degrees in the course, and westerly is subtracted. Naturally the direct way to make the correction is to add or subtract variation and deviation before applying to the C.C. This is most conveniently done by following the algebraic rule. If both quantities have the same sign, add the two and prefix the sign. If the quantities have different signs, subtract the less from the greater and prefix the sign of the greater to the answer.

Examples:

1.—Compass course, 195°. Variation, 20° W. Deviation, 5° W. Required, true course. Westerly error is always a minus quantity.

Hence:

Var.	$-20°$	C. C.	$195°$
Dev.	$-\ 5°$	Error	$-\ 25°$
Error	$-25°$	T. C.	$170°$

2.—C. C., 195°. Var., 20° E. Dev., 5° E. Required, T. C. Easterly error is always a plus quantity. Hence:

Var.	$+20°$	C. C.	$195°$
Dev.	$+\ 5°$	Error	$+\ 25°$
Error	$+25°$	T. C.	$220°$

3.—C. C., 195°. Var., 20° E. Dev., 5° W. Required, T. C.

Var.	$+20°$	C. C.	$195°$
Dev.	$-\ 5°$	Error	$+\ 15°$
Error	$+15°$	T. C.	$210°$

4.—C. C., 195°. Var., 20° W. Dev., 5° E. Required, T. C.

Var.	$-20°$	C. C.	$195°$
Dev.	$+\ 5°$	Error	$-\ 15°$
Error	$-15°$	T. C.	$180°$

Given the T. C., Var., and Dev. to find the C. C. to be steered, the navigator reverses the former process by changing the signs prefixed to easterly and westerly

errors. Easterly becomes minus and westerly plus.

Examples:

1.—T. C., 170°. Var., 20° W. Dev., 5° W. Required, C. C.

Var.	+20°	T. C.	170°
Dev.	+ 5°	Cor.	+ 25°
Cor.	+25°	C. C.	195°

2.—T. C., 180°. Var., 20° W. Dev., 5° E. Required, C. C.

Var.	+20°	T. C.	180°
Dev.	− 5°	Cor.	+ 15°
Cor.	+15°	C. C.	195°

The student will note that these are reverse workings of the first and fourth examples of the correction of a C. C. to find T. C. and they bring us back to our former C. C. A little practice will convince the student that the new method is easier than the old. Each method is illustrated in this book, since both are still in use.

LEEWAY

Leeway is, of course, not an error of the compass; but as it has to be considered in the correction of compass courses in dead-reckoning, it is convenient to introduce the subject here. A vessel sailing on a wind, or even with the wind abeam, will slide off to leeward more or less. Consequently her actual course will not be that indicated by compass, even when corrected for variation and deviation.

To find the leeway. — Experienced sailors can estimate the leeway by the angle between the vessel's wake and her keel. A good plan, however, is to heave the log, then bring the line to the centre of the compass, and its angle with the vessel's course will show the amount of leeway.

To correct for leeway.— Leeway on the starboard tack is the same as westerly variation. Leeway on the port tack is the same as easterly variation. The corrections are made in the same way. A glance at the diagram will make this clear. The vessel heading N.E. on the starboard tack and

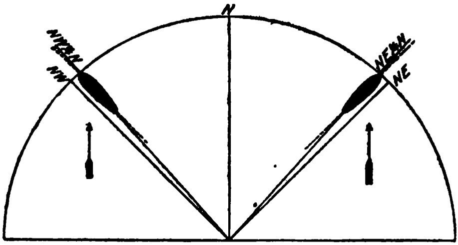


DIAGRAM OF LEEWAY

making a quarter-point of leeway is actually going N.E.¼N. The vessel on the port tack heading N.W. and making a quarter-point of leeway is really going N.W.¼N.

A good point to remember is this: leeway on the port tack and westerly variation or deviation are opposed to one another, and the same is true of leeway on the starboard tack and easterly error. For example, you have a quarter-point westerly variation, no deviation, and a quarter-point leeway on the port tack; the leeway and variation counterbalance one another, and the compass course is the true course. The form given in the following examples

for practice is that used in computing a vessel's dead-reckoning:

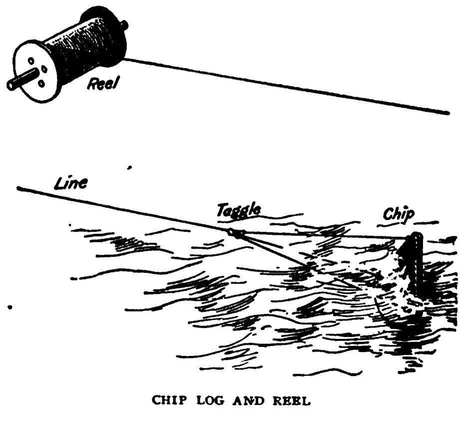
Compass course	Leeway	Variation	Deviation	True course
S.W.-by-W.	¼pt. Port	½pt. W.	¼pt. W.	S.W.½W.
E.-by-S.	3° Starb.	16° W.	10° E.	E.¼S.
N.N.E.½E.	¼pt. Star.	1 pt. E.	2 pts. W.	N.-by-E.¼E.
S. 42° E.	6° Port	20° W.	25° E.	S. 31° E.
S. 33° W.	3° Starb.	5° E.	3° W.	S. 32° W.

The student should set himself many problems of this kind for practice, and should not attempt to go further with this subject until he has mastered this one matter. Endless difficulty will otherwise be the result. A good method of study is to use the turning-card mentioned under the head of variation. But you must in the end be able to work without it. For instance, in the first example proceed thus: Port tack and westerly variation are opposed; that leaves a quarter-point westerly, which added to a quarter-point westerly (deviation) gives a half-point westerly correction; a half-point to the left of S.W.-by-W. is S.W.½W. In the second example, starboard-tack leeway and westerly variation add, giving 19° westerly correction; subtract 10° and you have 9° westerly left;

9°, or about three-quarters of a point, to the left of E.-by-S. is E.¼S.

THE LOG

There are two kinds of logs, the chip log and the patent or taffrail log. The principal parts of the chip log are the chip, the reel, the line, and the toggle. A second-glass is used for measuring the time.



CHIP LOG AND REEL

The chip is a triangular piece of wood, rounded on its lower edge and ballasted with lead to make it ride point up. The toggle is a little wooden case into which a peg, joining the ends of the two lower lines of the bridle, is set in such a way that a jerk on the line will free it, causing the log to lie flat so that it can be hauled in. The inboard end of the line is wound around the reel. The first 10 or 15 fathoms of line from the log-chip are called "stray line;" and the end of this is distinguished by a mark of red bunting 6 inches long. Its purpose is to let the chip get clear of the swirl under a vessel's counter before reckoning begins.

The knots, as they are called, are distinguished by running pieces of fish-line through the strands to the number of one, two, three, etc. A piece of white bunting, two inches long, marks every two-tenths of a knot. This is because the run of a ship is recorded in knots and tenths.

A new log-line should be soaked in water a few days before marking, and always before leaving port you should soak your line and then see that the marks are all at the proper distances.

The log-glass, in appearance like an hour-glass, measures 28 seconds. For high rates of speed, a 14-second glass is used, and then the number of knots shown by the line must be doubled. In damp weather a watch is better than a sand-glass.

The principle of the chip log is that the length of a knot bears the same ratio to the nautical mile (6086 feet) as the time of the glass does to the hour. Hence we get this proportion: As the number of seconds in an hour is to the number of feet in a mile, so is the number of seconds in the glass to the number of feet in the knot.

$$3600 : 6086 :: 28 \text{ sec.} : x$$
$$x = 47 \text{ feet } 4 \text{ inches.}$$

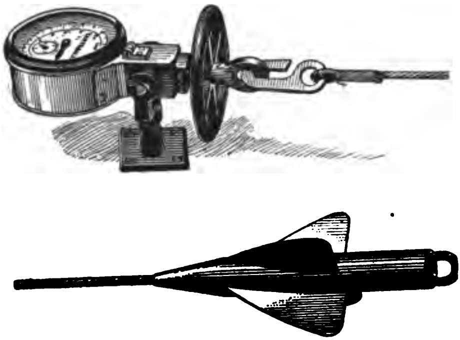
The speed of the ship is recorded in the log-book in knots and tenths of a knot.

How to heave the chip log.— Have an assistant to hold the glass. See that all the sand is in the bottom. Heave the log-chip well out to leeward from the stern, and hold the reel so the line will run freely. As soon as the stray line is out call "Turn," and the assistant must turn the glass quickly and start the sand running. The instant the sand has passed down

the assistant must call "Stop," and you check the line. Note the number of knots and tenths and haul in.

The chip log should be hove every hour. If the speed varies between hours it must be estimated, or the log hove again.

The patent or towing log consists of a dial, a line, and a rotator of screw-propel-



PATENT OR TOWING LOG

ler form. The action of the water on the rotator, which is at the end of the line and thrown overboard, causes the line to make

a certain number of twists a minute. These twists are proportional to the speed of the vessel, and they move the machinery of the dial, which records miles and fractions of a mile.

In setting a taffrail log to work, you must note where the dial stands at the time when you throw over the rotator. The reading of the log is noted in the log-book once an hour, and whenever the course is changed.

Both logs are liable to error. The rotator of the patent log slips sometimes, and that underrates the distance gone. Usually, however, it overrates. The chip log is likely to underrate with a following sea, which causes the chip to "come home," and to overrate a little with a head sea.

With both logs you must allow for currents. If sailing in a current known to be against the ship, you must deduct its rate from that recorded by the log. If sailing with the current, you must add its rate.

Reason: The log measures your speed through the water. What you wish to as-

certain is your actual movement over the surface of the globe.

Example: Between Brenton's Reef Light-ship and Cuttyhunk, bound east, speed by chip log was 10 knots, tidal current setting to the eastward $1\frac{1}{4}$ knots per hour; what did the ship make per hour? *Ans.*, $11\frac{1}{4}$ knots.

Again: At sea in the Gulf Stream, heading S.-by-W., patent log between 8 A.M. and 12 M. registered 32 miles, stream running N.-by-E. 2 knots per hour; what was the actual distance made? *Ans.*, 24 miles.

Directions for making allowance for currents setting diagonally across the course will be given in the proper place. The existence of a known current, its direction and speed, and the length of time the ship is affected by it, should be entered in the log. The necessary allowance for its effect on the ship's run is made by the navigator when computing his day's reckoning.

In shallow water, but out of sight of landmarks, a vessel drifting in a tideway may use a ground log. This is a common log-line with a hand lead attached, and it shows the actual speed of the ship over the *ground.*

THE LEAD-LINE

The lead is used to ascertain the depth of water, and, when necessary, the character of the bottom. There are three kinds of leads: the hand lead, coasting lead, and deep-sea lead. The first weighs from 7 to 14 lbs., and has markings to 20 fathoms. The second weighs from 25 to 50 lbs., and is used up to 100 fathoms. The third weighs from 80 to 150 lbs., and is used in depths over 100 fathoms. The hand lead is marked thus:

2	fathoms,	2 strips of leather.
3	"	3 " "
5	"	a white rag.
7	"	a red rag.
10	"	a piece of leather with a hole in it.
13	"	same as at 3.
15	"	" " 5.
17	"	" " 7.
20	"	with 2 knots.

Large hand leads and coasting leads are marked above 20 fathoms with an additional knot at every 10-fathom point (30, 40, 50, etc.), and a single knot at each intervening 5-fathom point (25, 35, 45, etc.).

The large hand leads, coast and deep-sea leads are hollowed out on the lower end so that an "arming" of tallow can be

put in. This will bring up a specimen of the bottom, which should be compared with the description found on the chart.

All first-class sea-going vessels should discard the deep-sea lead for Sir William Thompson's sounding-machine. This apparatus consists of a cylinder around which are wound about 300 fathoms of piano wire. To the end of this is attached a heavy lead. An index on the side of the instrument records the number of fathoms of wire paid out. Above the lead is a copper cylindrical case in which is placed a glass tube open only at the bottom and chemically colored inside. The pressure of the sea forces water up into this tube, as it goes down, a distance proportionate to the depth, and the color is removed. When hoisted, the tube is laid upon a prepared scale, and the height to which the water has been forced inside shows the depth in fathoms on this scale.

CHARTS

A chart is a map of an ocean, bay, sound, or other navigable water, showing the conformation of the coasts, heights of mountains, the depth at low-water, direction and velocity of tidal currents, location, character, height and radius of visibility of all beacon lights, location of rocks, shoals, and buoys, and nature of the bottom wherever soundings can be obtained.

The top of the chart is generally north. If for any reason it is otherwise, north will be indicated by the north point of a compass-card printed somewhere on the chart.

On the majority of small charts, such as those of bays, harbors, and sounds, the compass on the chart includes the variation; that is, its north point is slewed east or west, just as that of a real compass (without deviation) would be in that place. In laying off courses by such a compass you do not have to allow for variation, because it is already allowed for. On large charts, such as that of the North Atlantic, the compass is printed true, and the variation is indicated by lines marked with the direction and amount.

Parallels of latitude are shown by straight lines across the chart. The degrees and minutes are marked on the perpendicular border.

Meridians of longitude are shown by straight lines up and down the chart, and the degrees and minutes are recorded on the horizontal border.

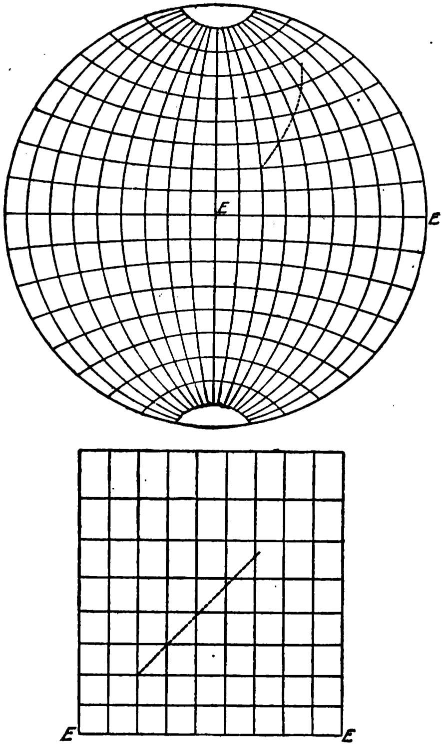
The navigator should know the varieties of buoys. Channels on the United States coasts are indicated by red buoys with even numbers situated on the starboard side coming in from the sea, and black buoys with odd numbers on the port side.

Buoys with black-and-white perpendicular stripes are in mid-channel and must be passed close to.

Buoys with red-and-black horizontal stripes indicate obstructions with channels on both sides.

The abbreviations on charts are easily understood.

Soundings on plain white are in fathoms; those on shaded parts are in feet. On large ocean charts fathom curves, showing the range of soundings of 10, 20, 30, 40, etc., fathoms are shown. They are of great as-



SPHERE COMPARED WITH MERCATOR'S CHART

sistance in taking soundings as you approach a coast.

A light is indicated by a red and yellow spot. F. means fixed; Fl., flashing; Int., intermittent; Rev., revolving, etc.

An arrow indicates a current and its direction. The speed is always recorded.

Rocks just under water are shown by a cross surrounded by a dotted circle; rocks above water, by a dotted circle with dots inside it.

The charts used by mariners, except in great-circle sailing, are called Mercator's charts. Speaking roughly, this chart is constructed on the imaginary theory that the earth is cylindrical. Hence the meridians of longitude, which in a sphere (see diagram) converge at the poles, are opened out and become straight, parallel lines. This compels a stretching out in width of everything represented in high latitudes. To preserve the geographical relations the length is also stretched proportionately, so that although everything in high latitudes is on too large a scale as compared with places in lower latitudes, the courses and distances measured on a chart are correct. The advantage of a chart made in this way is that it

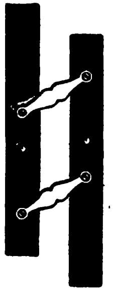
enables the course of a ship to be represented by a straight line, whereas on a sphere it would be—and truthfully so—a curved one.

In *very* high latitudes the inexactness of a Mercator's chart reveals itself fully. It is quite impracticable for polar navigation. For instance, how can you steer for the north pole on a chart whose meridians never come together at any pole, but are infinitely prolonged parallel lines? Owing also to this inexactness the bearings of distant objects are not always quite correct when laid down in straight lines on the chart. But, taking it all in all, the Mercator's chart is the one best adapted to the daily needs of the mariner.

By means of the chart the navigator may at times sail along a coast in clear weather without having recourse to any other instruments of navigation than the compass and lead-line.

The instruments used in consulting the chart are the parallel rules, dividers, and course-protractor.

The parallel rules are made of ebony or gutta-percha. They are connected by cross-pieces of brass, working on pivots in such a way that the rules may be spread apart



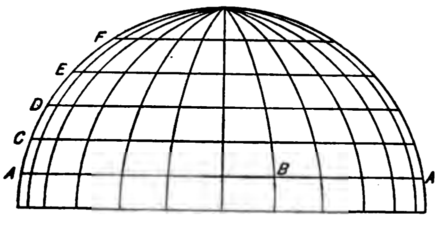
PARALLEL RULES

or pushed together, but will always remain parallel to each other.

They are used to determine the direction of courses. For instance, you wish to find the course from Sandy Hook Light-ship to Fire Island Light. Lay the parallel rules so that one edge cuts both places. Now slide first one rule and then the other, holding the unmoved one down firmly so as to retain the direction till the edge cuts the centre and circumference of the compass printed on the chart. The edge, if the direction has been preserved, will indicate the course.

The dividers are used to measure distance. On small charts take your distance from the scale of nautical miles; on large ones, from the latitude scale at the side of the chart. A minute of latitude is always a mile, because parallels of latitude are equidistant at all parts. A minute of longitude is a mile only at the equator, for the meridians are always coming nearer and nearer together, till at the pole they join and there is no longitude

at all. Yet, as every parallel of latitude runs all the way around the earth, it is a circle and contains 360°. The distance from A to B will be the same number of degrees, minutes, and seconds whether measured on parallel A or parallel E, but it will not be the same number of miles. But the distances from A to C, from C to D, and from D to E must be the same on any meridian, because the lines A, C, D, and E are parallel. That is why distance is measured on the latitude scale.



MINUTES VERSUS MILES

Long courses are most conveniently shaped by the course-protractor. Indeed, it is a waste of time to use anything else on a chart which shows the meridians. A course-protractor is simply a piece of trans-

parent horn or celluloid, with a compass-card printed on it and a string hanging from the centre of the card. Put the protractor down so that the meridian of the compass is exactly over a meridian of the chart, and stretch the string along your course. It will cut the point of the compass-card indicating the direction. You must, of course, remember that this gives a true course, and make the allowance for variation.

You can allow for the variation, however, by making the north point of your protractor compass point as far east or west of the meridian as the variation is.

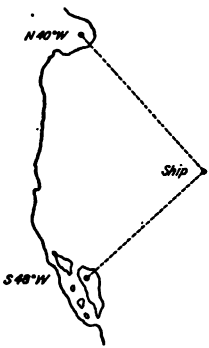
CHART SAILING

To find the position of the ship.—The best method is that by cross-bearings. Select two objects marked on the chart, so far apart that each will bear close to 45° off the ship, but in opposite directions. Take accurate bearings of each. Correct the bearings for deviation. Then with the parallel rules carry the bearing of one object from the compass-card printed on the

chart to the object itself, and rule a pencil line. Do the same with the other object. The intersection of the two lines will be the position of the ship at the time the sights were taken.

Other good methods require a knowledge of the use of the sextant, and will be introduced later in this book.

Having established the position of your vessel either by cross-bearings or by running close aboard of a light or buoy whose position is marked on the chart, you give your helmsman the first course. This course has been ascertained by the parallel rules and dividers according to the method already described.



MAP OF CROSS-BEARINGS

To find the distance between two places on the chart.—If the course is due north or south, measure the distance and refer it to the latitude scale on the side of the chart precisely opposite the course. The number of min-

utes in the distance as found there will be the number of miles.

If the course is due east or west, proceed in the same way.

If the course is diagonal, refer the distance to that part of the latitude scale opposite the middle of the course.

The proper method is to take off the scale at the side of the chart with the dividers a convenient unit, such as two miles or five miles, and find how many times it is contained in the course.

On plane charts of small expanses, such as harbors or bays, take your unit of measurement from the scale of nautical miles to be found on the chart.

To find the latitude of a place on the chart.—Measure the distance of the place from the nearest parallel. Take the dividers to the graduated border at the side of the chart, and put one leg in the same parallel. The other should be in the graduated border at the latitude required.

To find the longitude of a place on the chart.—Proceed in precisely the same manner, but use a meridian and the longitude border at the top or bottom of the chart.

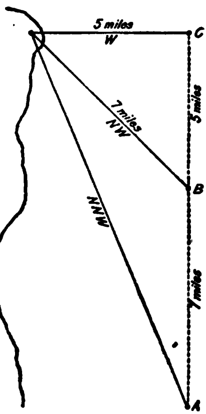
To mark the ship's place on the chart.—This is to be done at sea after finding the latitude and longitude. "With the dividers take from the graduated meridian the given latitude; mark this on the meridian nearest the given longitude; lay the edge of a pair of parallel rulers on a near parallel, and work one side of them to the exact latitude you have marked on the meridian; then with the dividers take the given longitude from the graduated parallel [at the top or bottom of the chart]; lay this down along the edge of the parallel rulers which already mark the latitude, and you have the ship's place" (Qualtrough).

To berth sailing-ship at anchorage.—Select the spot on the chart where you wish to anchor. Note the soundings at mean low-water and have your cable ranges overhauled for at least three times that depth. Draw a circle around the spot, with a radius about three times the length of the cable to be let go. See if you will have swinging room at all points on the circumference of the circle, and also plenty of room for getting under way with the wind in any direction, for you may not be able to bring up just at the centre of your circle.

Now lay down cross-bearings on the circumference of your anchorage at the side from which you expect to approach it. When you get those bearings on your compass, round up and let go. After anchoring ascertain the exact position of your vessel by new cross-bearings, and note the same in the log.

In setting a course on a chart, carefully note the direction and speed of the tidal currents. Refer to your tide tables and find out just where the tide is and make allowance accordingly. Remember that the tide ebbs 6 hours and flows 6 hours, but in many places the currents do not change for some time after the hours of high and low water. These points you can learn only from local watermen, or from the pages of the *Atlantic Coast Pilot* and similar works.

To find the ship's position when sailing along the land.—Take a compass bearing of a light or other prominent object when it is 2, 3, or 4 points off the course. Take another bearing when it has doubled the first and is 4, 6, or 8 points off the course. The distance run by the ship between the two bearings will be her distance from

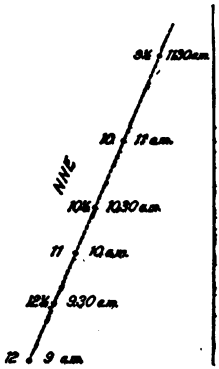


COASTWISE BEARINGS

the observed object at the second bearing.

In the diagram the ship at A heading north finds the light bearing N.N.W., 2 points off her course. At B she finds it bears N.W., 4 points off. The log makes the distance from A to B 7 miles. The distance of the light from the ship at B will be seven-tenths of this. The commonest form of this problem is that used at positions B and C, with the object 4 points off the course and exactly abeam. This is known as the bow-and-beam bearing. The navigator will find cases in which the other form is convenient. This method should be practised continually, as it is the standard method in coastwise navigation. It is also valuable in establishing a final position with reference to the land when about to go to sea.

How to use compass, log, and lead in a fog.—Take a piece of tracing-paper and rule a meridian on it. Take casts of the lead at regular intervals, noting the time at which each cast is taken, and the distance logged between each two. The compass shows the course. Now rule a line on the tracing-paper in the direction of your course. Measure off on it by the scale of miles of your chart the distances run between casts. Opposite each cast note the time and the depth ascertained. It is a good thing to add also the character of the bottom. Now lay your tracing-paper down on the chart, which can be seen through it, in the neighborhood of the position you believed yourself to be in when you made the first cast. If your chain of soundings agrees with those on the chart right under your course, all is



CHAIN OF SOUNDINGS

right. If not, move the tracing-paper about, keeping the meridian line due north and south, till you find the place on the chart that does agree with you. That is where you are. You will not find two places where you can get that chain of soundings on the same course and at the same distances.

This is the *only* method by which a ship's position can be found with any certainty on soundings in thick weather. There is no excuse whatever for the man who runs his vessel ashore, if he has not tried this.

DEAD RECKONING

To ascertain the position of a ship at sea by keeping account of the courses and distances which she sails, we proceed on the theory that small sections of the surface of the earth are flat. The whole matter then resolves itself into the solution of right-angled triangles. A single glance will show the student that any of the courses ruled on the diagram chart unite with the parallels and meridians in forming

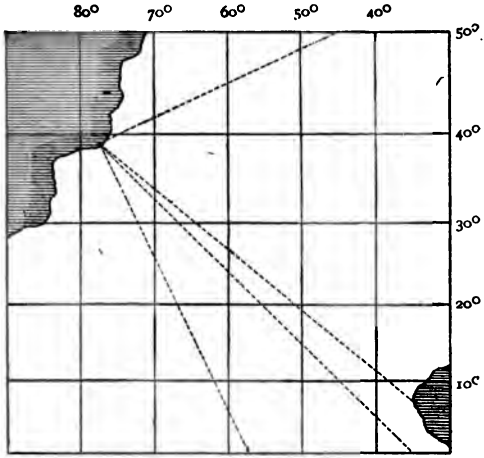


DIAGRAM CHART

series of right-angled triangles. The only cases in which no such triangles exist are those of sailing due east and west or due north and south.

The problems to be solved in sailing on the open sea out of sight of land are these: Having left a known point and sailed so many miles in such and such direction, what latitude and longitude have we arrived at, and what are the course and dis-

tance thence to our point of destination?

If you are sailing due north or south, the problem is extremely simple. Suppose your position at noon to-day is lat. 41° 15′ N., long. 40° W., and up to noon to-morrow you sail 280 miles north (true). It is obvious that the longitude will remain unchanged. The latitude will be 280 minutes, or 4° 40′, farther north. That 4° 40′ is called the difference of latitude, and in this case it is obviously to be added to to-day's latitude, because we have been increasing our latitude. The ship's position at to-morrow noon, then, is lat. 45° 55′ N., long. 40° W.

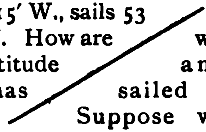
Hence we learn that the distance by which a ship changes her latitude north or south is called difference of latitude.

In sailing due east or west, however, the matter is not so simple, because only on the equator are a nautical mile and a minute of longitude the same thing. But if we have a table giving us the number of miles in a degree of longitude at every distance north or south of the equator (which means in every latitude), we can easily find the longitude. For instance, a ship in lat. 42° N. sails true east 100 miles; how much

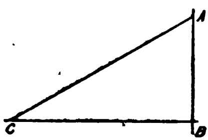
does she alter her longitude? A degree of longitude in lat. 40° measures 44.59 miles. She changes her longitude by 2° 10.8′ or 2° 10′ 48″—a tenth of a minute being 6″.

The number of *miles*, then, which a ship makes east or west is called *departure*, and it must be converted into degrees, minutes, and seconds in order to find the difference of longitude.

But nine times out of ten a ship sails a diagonal course. Suppose a vessel in lat. 40° 20′ N., long. 60° 15′ W., sails 53 miles S.W.-by-W.½W. How are we to find her new latitude and longitude? She has sailed a course like this:



Suppose we draw a perpendicular line to represent a meridian, and a horizontal one to represent a parallel. Then we shall have the triangle ABC, in which the line AC represents the distance and direction, while the angle at A is the angle of the course with the meridian. If now we can ascertain the length of AB, or the distance by which



she has gone to the south, we shall have the difference of latitude; and if we can get the length of the line BC, we shall have the departure and from it the difference of longitude. From these two factors we get the new latitude and longitude.

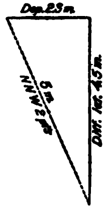
This is a simple problem in trigonometry, but no navigator need know trigonometry, because Tables I. and II. of Bowditch solve all possible problems of this kind for him, and he needs only arithmetic.

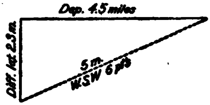
The complete Navigation Tables can be purchased separate from the rest of the work, under the title *Useful Tables*, for $2.25.

Table I. is marked at the top with the different courses from ¼ point up to 4 points. In three adjoining columns are found distance, difference of latitude, and departure, marked Dist., Lat., and Dep. If you are sailing on any particular course, say N.N.E., you go to the table for 2-point courses, look in the distance column for the distance you have made by your log, and opposite to that distance you will find your diff. lat. and dep.

At 4 points diff. of lat. and dep. become equal, because the course is precisely half

way between no points and 8 points. On any course *less* than 4 points diff. lat. is greater than dep., because you go more north or south than east or west. On any course *greater* than 4 points dep. is greater than diff. lat., because you go more east or west than north or south. And the relations of the two elements are simply reversed, as may be seen by the diagrams. In a 2-point course, the diff. lat. is the same as the dep. in a 6-point course, the complement of a 2-point course. Hence, in using the tables, as soon as you have a course over 4 points, you begin at the last page of the tables and read *up* from the bottom, noting that while *dist.* remains in the same place, lat. and dep. are reversed.





Suppose you have sailed 28 miles N.-by-W.¼W. Opposite 28 in the dist. column under 1¼-point courses you find diff. lat. 27.2 miles and dep. 6.8 miles.

Suppose you have sailed 40 miles E.-by-N. Under 7-point courses you find (read-

ing from the bottom up) opposite dist. 40, diff. lat. 7.8, dep. 39.2.

Table II., Bowditch, contains the same elements worked for courses in degrees. You should now be prepared to work such examples as these:

A ship leaving lat. 36° 15′ N., long. 47° 48′ W., sails S.E.-by-E. 78 miles. Required the diff. lat., the dep., and the new lat.

Ans. Diff. lat. 43.3, dep. 64.9, new lat. 35° 31′ 42″ N.

(Bear in mind that a tenth of an hour or a degree is 6 minutes; a tenth of a mintue, 6 seconds.)

A ship leaving lat. 28° 15′ S., long. 43° 18′ E., sails 49 miles N.W. What are the diff. lat., dep., and new lat.?

Ans. Diff. lat. 34.6 miles, dep. 34.6, new lat. 27° 40′ 24″ S.

A ship leaving lat. 1° 10′ N., long. 16° 5′ W., sails S.S.E. 168 miles. Give same elements.

Ans. Diff. lat. 155.2 miles, dep. 64.3 miles, new lat. 1° 25′ 12″ S.

A ship leaving lat. 15° 15′ N., long. 121° 31′ E., steers 63°, 64 miles. Give same elements.

Ans. Diff. lat. 29.1, dep. 57, new lat. 15° 44′ 6″ N.

The full rule for finding the new lat. is as follows:

When the old lat., known as *lat. left*, and diff. lat. are both N. or both S., add them; when one is N. and the other S., subtract the less from the greater, and the remainder, named N. or S. after the greater, will be the new lat., known as lat. *in*.

The next step is to find the diff. long., and from it the new, or long. in. The proportions of right-angled triangles are such that all you have to do is to obey the following rule:

Find the mid. lat. between that of yesterday and that of to-day. Go to the page in Table II., marked with the number of degrees of this mid. lat. which you have just found, and seek in the *diff. lat.* column for the amount of your *dep.* Opposite to it in the *dist.* column will be the figures indicating the number of *minutes* in the *diff. long.*

Example: A ship in lat. 36° 15′ N., long. 52° 18′ W., sails on 34°, 60 miles; required the lat. and long. in.

Table I., under the head of 3-point courses, gives for 60 miles diff. lat. 49.9 miles, dep. 33.3. The lat. in is, therefore, 37° 4′ 54″ N. To find the mid. lat. add

the lat. left and the lat. in, and divide by 2. Take the nearest degree as your answer. In this case the mid. lat. is 36° 39′ 57″, and as that is nearer 37° than 36° we take the former. Now turn to the page for 37° in Table II. Apply the dep. 33.3 in the lat. column; the nearest you can come to it is 33.5, opposite which in the dist. column is 42, which means that in lat. 37° a dep. of 33.5 miles will equal 42′ diff. long. Long. left was 52° 18′ W. We have made 42′ diff. long. to the eastward, thus diminishing our westerly longitude. We subtract 42′ from 52° 18′ W., and get 51° 36′ W. as our long. in.

This process of working out the latitude and longitude is called *middle latitude sailing*, and by it the ordinary problems of dead-reckoning are solved. The cases which present themselves in the actual practice of navigation are three in number.

Case I.—Course and distance sailed being given, to find the diff. lat. and dep.

Case II.—The lat. and long. left and the course and distance being given, to find the lat. and long. in.

Case III.—The latitudes and longitudes of two places being given, to find the course and distance between them.

Cases I. and II. have been explained, except as to sailing true east or west, which is called *parallel* sailing. Here there is no diff. lat., and the lat. in is the mid. lat. To find the diff. long. apply the distance sailed, which in this case is also the departure, in the lat. column, and opposite it in the dist. column will stand the number of minutes in the diff. long.

To solve case III.—Subtract the less latitude from the greater, and reduce the remainder to minutes. Do the same with the two longitudes. Find the mid. lat. Go to the page in Table II. marked with the number of degrees in the mid. lat., and seek the diff. long. in the dist. column. Opposite to it in the lat. column will be the dep. Now seek in Table II. for the page where the diff. lat. and the dep. stand beside one another in their respective columns. The required dist. will stand opposite in the dist. column, and the course either at the top or bottom of the page, according as diff. lat. or dep. is the greater.

In using Tables I. and II., if the dist., lat., or dep. in your problem happens to be larger than those contained in the table, you can obviate the difficulty by dividing all your

elements by 10, because the relations of all the parts of a right-angled triangle one-tenth the size of yours will be just the same if you reduce all three sides to one-tenth. For instance, you have diff. lat. 304′; dep. 2694 miles. Divide both by 10 and you have 30.4 and 269.4, both of which are in the tables. With those you can find one-tenth of your distance, which take out and multiply by 10. The angles all remain the same, so the course is all right as it stands.

Example: A ship in lat. 42° 3′ N., long. 70° 4′ W., is bound for St. Mary's, lat. 36° 59′ N., long. 25° 10′ W. What are the course and distance?

Lat. left ....42° 03′ N.	Long. left ....70° 04′ W.
Lat. sought.......36° 59′ N.	Long. sought..25° 10′ W.
Diff. lat.......... 5° 04′	Diff. long.....44° 54′
Reduced to minutes = 304	Reduced to minutes = 2694
Middle lat........39° 31′.	

As the tables do not run beyond 300 miles, we take one-tenth of 2694 (the diff. long.), 269, and under 40° with this number in the dist. column we get 206.1 dep. out of the lat. column. Now we look for a place where the diff. lat. is 30.4 and the dep. 206.1. As we are working with one-tenth of the dep., we must do the same with 304, the diff. lat., or, in other words, put a decimal mark before the 4,

making it 30.4. We find under the head of $7\frac{1}{4}$ points diff. lat. 30.7, dep. 206.7, and opposite them the dist. 209. This is one-tenth of the real distance, 2090 miles. As the diff. lat. was southward and the diff. long. eastward, the course must be S. $7\frac{1}{4}$ points E., or E. $\frac{3}{4}$ S., or 98°.

EXAMPLES FOR PRACTICE

Required the course and distance from the Cape of Good Hope, lat. 34° 22′ S., long. 18° 24′ E., to St. Helena, lat. 15° 55′ S., long, 5° 45′ W.

Ans. Course 310°, dist. 1717 miles.

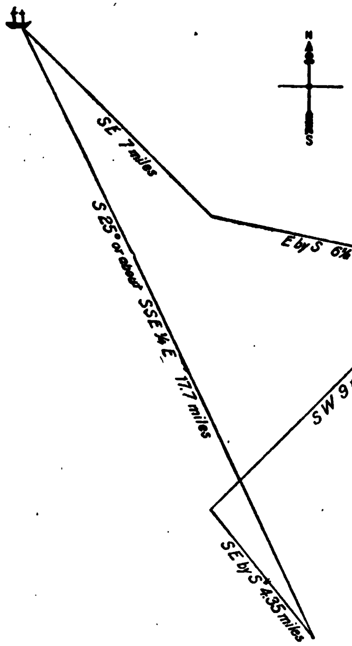
Required course and distance from Pernambuco, lat. 8° 4′ S., long. 34° 53′ W., to Cape Verde, lat. 14° 45′ N., long. 17° 32′ W.

Ans. Course 37°, dist. 1720 miles.

A ship from lat. 2° 5′ N. and long. 22° 30′ W. sails W.S.W. 256 leagues (a league = 3 miles). Required her present lat. and long., and her course and dist. to St. Ann's Island, lat. 2° 15′ S., long. 43° 38′ W.

Ans. Lat. 2° 49′ S., long. 34° 20′ W., course 274°, dist. 559.6 miles.

Excellent practice may be had by laying off courses and distances on charts, and then working out the same by computation to see how near your two results will agree.



TRAVERSE COURSE FROM SANDY HOOK LIGHTSHIP

WORKING A TRAVERSE

If a ship sailed for 24 hours on one course, the student would now be ready to work out her latitude and longitude by dead-reckoning. But vessels usually change the course several times in the course of a day's run, and as the reckoning is only computed once a day—at noon—it becomes necessary to have a method of obtaining the result of several courses. This is called working a traverse, and it is the culmination of dead-reckoning.

Suppose a vessel to start from Sandy Hook lightship, lat. 40° 28′ N., long. 73° 50′ W., and sail in 24 hours S.E. 7 miles, E.-by-S. 6½ miles, S.W. 9 miles, and S.E.-by-S. 4.35 miles; where would she be at noon on the second day? The diagram shows us that she would be 17.7 miles about S.S.E. ¼E. of the lightship. The method of calculating such a compound course is called working a traverse, and is as follows:

Write out the various courses with their corrections for variation, leeway, and deviation, and the distance run on each. In four columns headed respectively N., S., E., W., put down the diff. of lat. and dep. for each course. Add together all the north-

ings, all the southings, all the eastings, all the westings. Subtract to find the difference between northings and southings, and you will get the whole diff. lat. The difference between eastings and westings will give the whole dep.

With the whole diff. lat. and whole dep., seek in Table 2 for the page where the nearest agreement of lat. and dep. with your figures can be found. The number of degrees at the top or bottom of the page (according as diff. lat. or dep. is greater) will give you the *course made good*. The distance made good is found in dist. column, opposite the agreeing lat. and dep.

Find the lat. in, as already explained.

Find the long. in, as already explained.

Example: A ship in lat. 31° 15′ N., long. 68° 30′ 15″ W., sails by compass 36 miles E.-by-S., with 1 pt. W. var., ¼-pt. E. dev., ½-pt. port-tack leeway; 22 miles S.S.E. with some variation, ½-pt. E. dev., ¼-pt. starboard-tack leeway; 28 miles S. by E. with same variation, ¼ W. dev., ¼-pt. port-tack leeway; and 31 miles S. with ¾-pt. W. var., ½-pt. E. dev., and ¼-pt. port-tack leeway. Required the course and distance made good and the new lat. and long.

Comp. course	Variation	Deviation	Leeway	True course	Dist.	N.	S.	E.	W.
E.-by-S.	1 pt. W.	¼E.	½pt. Port	E. ¾S.	36	..	5.3	35.6	..
S.S.E.	1 pt. W.	½E.	¼pt. Starb.	S.S.E. ¾E.	22	..	18.9	11.3	..
S.-by-E.	1 pt. W.	¼W.	¼pt. Port	S.S.E.	28	..	25.9	10.7	..
S.	¾pt. W.	½E.	¼pt. Port	S.	31	..	31	..	..
							81.1 Dif. lat.	57.6 Dep.	

Ans. Course made good S. 35° E., or 145°, dist. 99 miles.

Lat. left..............$31^\circ\ 15'\ 00''$ N.
Diff. lat..............$1^\circ\ 21'\ 06''$ S.
Lat. in..............$29^\circ\ 53'\ 54''$ N.

$31^\circ\ 15'\ 00''$ N.
$29^\circ\ 53'\ 54''$ N.
$2\,)\,61^\circ\ 08'\ 54''$
Middle lat........ $30^\circ\ 34'\ 27''$

Long. left............$68^\circ\ 30'\ 15''$ W.
Diff. long............$1^\circ\ 07'\ 00''$ E.
Long. in............$67^\circ\ 23'\ 15''$ W.

In this example there is no subtraction of southing and northing, or of easting and westing. Let us suppose a case, however, of a ship beating to the eastward, and forced to run off to the northwest by some accident. Omitting the corrections of the compass course for the sake of brevity, we should have a traverse like this:

Lat. left, 26° 30′ N.			Long. left, 48° 25′ W.		
Course	Distance	N.	S.	E.	W.
S.S.E.	12	..	11.1	4.6	..
N.E.¼E.	16	10.7	..	11.9	..
S.E.½E.	14	..	8.9	10.8	..
W.N.W.	13	5.0	..	..	12.0
		15.7	20.0	27.3	12.0
			15.7	12.0	
			4.3	15.3	

Course S. 74° E. Distance, 16 miles.

Lat. left....26° 30′ 00″ N.	Long. left.....48° 25′ W.
Diff. lat.... 4′ 18″ S.	Diff. long..... 17′ E.
Lat. in.....26° 25′ 42″ N.	Long. in......48° 08′ W.

Currents.—In case the ship encounters a known current setting diagonally across the course, multiply the rate of the flow by the number of hours and enter it as distance, and enter the direction as a course.

Example: A ship from lat. 36° 15′ S., long. 101° 14′ E., sails in 24 hours 30 miles 338° true, and 68 miles 276° true.

During 12 hours of the day she is in a current setting E.½S. at the rate of 2 knots per hour. Required her course and distance made good.

Course	Distance	N.	S.	E.	W.
338°	30	27.8	....	....	11.2
276°	68	7.1	....	....	67.6
E.½S.	24	....	2.4	23.9	....
		34.9			78.8
		2.4			23.9
		32.5			54.9

Ans. Course made good, N. 59° W., dist. 64 miles, or course, 301°.

HOVE TO

A sailing-vessel hove to in a gale comes up toward the wind and then falls off, and her course is a zigzag. To keep her reckoning note how she heads when she has come up as far as she will, and again when she has fallen off to the limit. The point half way between is to be called the course. For instance, she comes up to east and falls off to northeast. The course is east-northeast.

The leeway, variation, and deviation are applied to the course thus ascertained.

Different ships make different leeway, and the navigator must determine its extent by careful observation.

Every time she begins to come up she will go ahead a little. The speed of this progress or "drift" is entered as the rate in knots. The rest of the operation is the same as in working a traverse.

Example: A vessel in lat. 33° 14′ S., long. 60° 47′ E., is hove to on the starboard tack. She comes up to E.-by-S., and falls off to E.-by-N.; leeway, 6 points; drift, 2 knots per hour; variation, 22° E.; vessel hove to 24 hours. What is her position at noon of the second day? (See table on page 67.)

SHAPING THE COURSE

Having ascertained the position of the ship, it becomes necessary to ascertain the course required to sail to reach the port of destination. This may be done by using the chart, if the distance is small and the scale of the chart large. If the distance is considerable and the scale of the chart small, much inaccuracy will follow.

Comp. course	Leeway	Variation	True course	Dist.	N.	S.	E.	W.
E.	6 pts. Starb.	2 pts. E.	N.E.	48	33.9	..	33.9	..

Lat. left............$33^{\circ}\ 14'\ 00''$ S.
Diff. lat............$00^{\circ}\ 33'\ 54''$ N.
Lat. in.............$32^{\circ}\ 40'\ 06''$ S.

$$\begin{array}{r} 33^{\circ}\ 14'\ 00'' \\ 32^{\circ}\ 40'\ 06'' \\ \hline 2\,)\,65^{\circ}\ 54'\ 06'' \\ \hline 32^{\circ}\ 57' = 33^{\circ} \text{ middle lat.} \end{array}$$

Departure......33.9 in lat. 33°
$= 40'$ diff. long.

Long. left......$60^{\circ}\ 47'\ 00''$ E.
Diff. long......$00^{\circ}\ 40'\ 00''$ E.
Long. in.......$61^{\circ}\ 27'\ 00''$ E.

The course is, therefore, to be found either by mid. lat. or Mercator's sailing.

The course is found by mid. lat., according to the rule laid down in Case III. of dead-reckoning.

If the course is more than 4 points, mid. lat. will give a satisfactory result. But if the course is 4 points or less, owing to the construction of Mercator's charts with their expansion of the degrees to the north or south, error will creep in. Consequently Mercator's sailing must be employed. Mid. lat. is good for shaping any course if it is short, except in high latitudes, where the Mercator method should always be used.

To solve problems in Mercator's sailing the navigator must use Table III. This table contains the meridional parts corresponding to the increases in the charted lengths of the degrees of latitude. These parts are picked out by finding the degrees at the top or bottom of the table, and the minutes at the side. Thus the meridional parts corresponding to 19° 45′ are 1201.4; 9° 36′, 574.9; 29′, 28.8.

To shape the course and find the distance by Mercator's sailing.—Find the difference

between the meridional parts corresponding to the lat. in and lat. sought. Call this meridional diff. lat. With the meridional diff. lat. and the diff. long. find the course by searching in Table II. for the page where they stand opposite one another in the lat. and dep. columns. Under this course find the distance opposite the proper (*not* meridional) diff. lat.

Example: What are the course and distance from Sandy Hook Lightship, lat. 40° 28′ N., long. 73° 50′ W., to lat. 39° 51′ N., long. 72° 45′ W.?

Lat. in	40° 28′	Mer. parts	2644.5
Lat. sought	39° 51′	Mer. parts	2596.2
Proper diff. lat.	0° 37′	Mer. diff. lat.	48.3
Long. in	73° 50′ W.		
Long. sought	72° 45′ W.		
Diff. long.	1° 05′=65′		

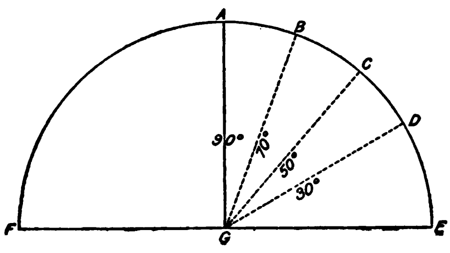
On the page in Table II. which has 37° at the top and 53° at the bottom we find 64.7 and 48.7 opposite one another. This is the nearest agreement to the meridional diff. lat. and the diff. long. that we can find. As the 48.7 is in the right-hand column we must read the table up from the bottom, and this gives us a course of 53°. Our course is, therefore, S. 53° E. Under

53°, applying our proper diff. lat., 37′, in the lat. column we find 37.3, opposite which is our distance, 62 miles.

NAVIGATION BY OBSERVATION

Navigation by observation is carried on by measuring the altitude of the sun, the moon, or a star, and computing from this and certain other data the latitude or longitude of the ship. The altitude of a celestial body is expressed in terms of degrees and minutes, and is that part of 90° contained between the body and the sea horizon.

An observer standing at the point G in the diagram would see the horizon at E

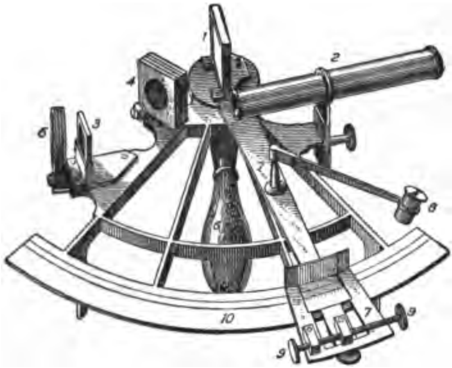


and F, and the apparent sky stretching from one side to the other in a semicircle, or rather hemisphere. Now a circumference of this semicircle is divided, like any other, into 180°. Supposing the sun to rise at E, at D it would be 30° high, at C 50°, at B 70°, and at A, immediately overhead, 90°. Going down the other side its altitude would continually decrease. From this we learn that the altitudes of celestial bodies range from 0 to 90°, for no matter in which direction we face the horizon the arc of the sky from the horizon point opposite us to the zenith, which is the point immediately overhead, will measure 90°.

The first element, then, required in any problem of navigation by observation, is the angular altitude of the celestial body in use. The measurement of this altitude is made by means of the sextant, or an instrument of the sextant family.

The principal parts of the sextant are shown in the accompanying sketch.

The sliding limb (No. 7) has a clamp sliding along the arc (No. 10). A screw passes through this clamp, and by tightening it the sliding limb is held firmly in any position at which it is placed. It can, however,



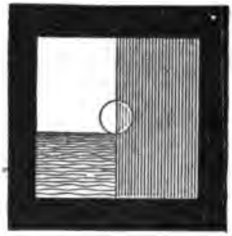
SEXTANT

1. Mirror.
2. Telescope.
3. Horizon-glass.
4. Shade-glasses.
5. Back Shade-glasses.
6. Handle.
7. Sliding limb.
8. Reading-glass.
9. Tangent screw.
10. Arc.

be further moved by very small advances by the use of the tangent screw (No. 9.)

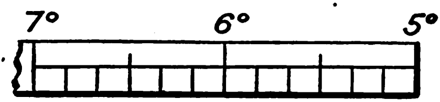
The instrument is held by the handle (No. 6) in the right hand, with the telescope towards the observer's eye. He must now direct the telescope towards that part of the sea which is directly beneath the celestial object to be observed. His line of sight will pass through the horizon-glass. He now moves the sliding limb until the image of the celestial body, reflected by the mirror (No. 1) appears in the horizon-glass. He then tightens the clamp screw,

described above, and by means of the tangent screw (No. 9) moves the sliding limb just a little more, so that the image "kisses" the horizon, which is seen through the transparent half of the horizon-glass. If he can make the image split on the two halves of the glass, as in the cut, the "contact," as it is called, will be all the more accurate. He now reads the angular altitude from the scale on the arc of the sextant by means of the reading-glass. The measurement is shown by a small vernier scale which runs along the oblong opening in the sliding limb.

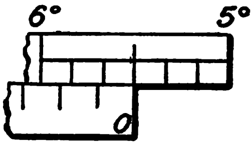


HORIZON-GLASS WITH SUN "KISSING SEA"

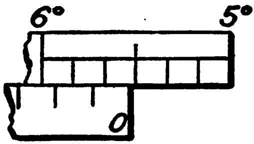
The arc itself is divided into degrees and sixths of a degree in this manner:



The vernier is divided similarly, but its parts represent minutes and sixths of a minute. To read the angle the zero point on the vernier is used as a starting-point. If it exactly coincides with one of the lines on the scale of the arc, that line gives the measurement of the angle; thus, in this case the angle is $5\frac{1}{2}°$, or $5° \ 30'$.



If, however, you find the zero point has passed a line of the arc, as in the second case shown, your angle is more than $5° \ 30'$, and you must look along the vernier to the left till you find the point where the lines do coincide. Then add the number of minutes and sixths of a minute shown on the vernier between zero and the point of coincidence to the number of degrees and minutes shown on the arc at the line which the vernier zero has passed, and the sum will be the angle measured by the instrument.



Some instruments have the arc cut to quarters of a degree, or 15′, and a quadrant is cut to thirds of a degree; the vernier showing minutes only. The sextant is the instrument most in use. The student will require some practice before being able to take and read an altitude of the sun, and a great deal before he can do anything with the stars. An hour's practice under an old mariner, however, will do him more good than a hundred pages of book instruction.

Regulate the shade-glasses to suit your eye. Those at the top of the instrument affect the image of the sun only, and serve to deaden its brilliancy. The back shade-glasses are used when the glare on the water is too powerful. You cannot get a good contact with your eyes dazzled.

ADJUSTMENTS

I. The mirror must be perpendicular to the plane of the instrument. Set the sliding limb at 60°. Hold the sextant face up. Place the eye nearly in the plane of the instrument opposite the apex and look into

the mirror. If the image of the arc in the mirror and the arc itself show in one unbroken line, the adjustment is correct; if the reflected image is lower, the glass leans backward; if it is higher, the glass leans forward. Straighten the glass by turning the screws at its back.

II. The horizon-glass must be perpendicular to the plane of the instrument. Set the zero of the vernier to the zero of the arc. Hold the sextant almost face upward, and look through the sighting-vane and the horizon-glass at the horizon. If the horizon line and its image (seen in the clean and silvered parts of the glass) do not coincide, turn the screw at the back of the glass till they do.

III. The horizon-glass must be parallel to the mirror. Set the zero of the vernier to the zero of the arc. Hold the instrument as in taking an observation, and look at the horizon. If the line and its image in the silvered part of the horizon-glass coincide, the adjustment is correct; if they do not show in an unbroken line, adjust the horizon-glass by turning its screw.

IV. The line of sight of the telescope must be parallel to the plane of the instru-

ment. "Screw in the telescope containing the two parallel wires, and see that they are turned until parallel with the plane of the sextant; then select two stars, at least 90° apart, and make an exact contact at the wire nearest the plane of the instrument, and read the measured angle. Move the sextant so as to throw the objects on the other wire, and if the contact is still perfect, the axis of the telescope is in its right situation and the telescope adjustment is correct. If the images have separated, it shows that the object end of the telescope droops towards the plane of the sextant, and if the images overlap, it proves that the object end of the telescope points away from the plane of the instrument. This will be rectified by the screws in the collar of the sextant. A defect in the telescope adjustment always makes angles too great" (Patterson).

INDEX ERROR

It is better to let your instrument alone after once adjusting it. If you continually torture it, you will get it hopelessly out of

order. Error remaining after adjustment is called index error. It is found thus: Set the sliding limb at 0, hold the instrument perpendicularly, and look at a star. Move the sliding limb forward or backward till the star and its image coincide in the horizon-glass. Clamp the sliding limb and read the angle, which is the index error. If zero on the vernier is to the left of zero on the arc, the index error is to be subtracted; if it is to the right, the error must be added. Index error is usually expressed thus: I. E. $1^\circ\ 15'-$; or I. E. $2^\circ\ 8'+$. The horizon and its image brought into line can also be used.

HINTS ON TAKING ALTITUDES

Learn to take a single sight with accuracy. It is a good thing to take the mean of three or four sights when working longitude, but you cannot always do that.

Oscillating the instrument from right to left and back, while taking a sight, will make the image skim the horizon so that you may make sure of the point vertically under it.

When fog obscures the horizon from the

deck, you can sometimes get a new horizon by lowering away a boat.

In rough weather try to get the mean of three or four sights. You thus reduce the amount of error caused by the pitching of the ship.

Ascertain the index error before taking every altitude or set of altitudes. The error is liable to change.

CORRECTING THE ALTITUDE

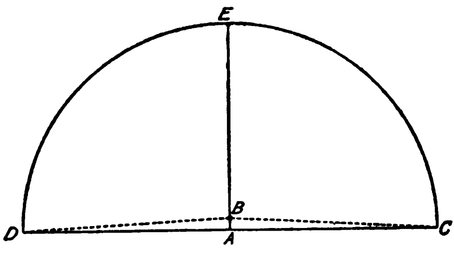
Certain corrections have to be made to all altitudes taken with a sextant. These corrections are for dip of the horizon, refraction, and in the cases of the sun and moon, for semi-diameter.

The altitude used in the computation of the ship's position is that of the centre of the celestial body. As already explained, the sextant gives the altitude of the upper or lower edge.

For navigational purposes we assume that the diameter of the sun equals 32′ of the arc of the sky. Therefore, if you take the altitude of the lower edge you must add 16′, or half the diameter, to get the

altitude of the centre. If you take the altitude of the upper edge, as you might have to do in case the lower one was obscured by clouds, you must subtract 16′. Stars, having no apparent diameter, do not call for this correction.

Dip of the horizon means an increase in the altitude caused by the elevation of the eye above the level of the sea. The simplest illustration of this is afforded by the accompanying figure. If the eye is on the



level of the sea at A, it is in the plane of the horizon CD, and the angles EAC and EAD are right angles, or 90° each. If the eye is elevated above A, say to B, it is plain that the angles EBC and EBD are

greater than right angles, or, in other words, that the observer sees more than a semicircle of sky, and hence all measurements made by the sextant are *too large;* hence the correction for dip is *always subtracted* from the altitude.

Table 14 gives the corrections for various heights of the eye. It is the navigator's business to measure the height of his eye above the water-line of his ship at such places as he may wish to stand when taking altitudes.

Dip is subject to variations. Much difference between temperatures of air and water displaces the horizon. Increase in temperature increases error in dip as given in table. Increase in wind diminishes it. Sea water colder than air, horizon raised, alt. too high; water warmer, horizon depressed, alt. too low.

Error decreases as height of eye increases. When error is likely, take alt. from highest point available.

Alt. can be taken against a shore line closer to ship than sea horizon would be. For this use Table 15.

Refraction is a curving of the rays of light caused by their entering the earth's

atmosphere, which is a denser medium than the impalpable ether of the outer sky. The effect of refraction is frequently seen when an oar is thrust into the water and looks as if it were bent.

Refraction always causes a celestial object to appear higher than it really is. This phenomenon is greatest at the horizon and diminishes towards the zenith, where it disappears. Table 20 gives the corrections for mean refraction, which are always subtracted from the altitudes. In the higher altitudes, select the correction for the nearest degree.

Avoid taking low altitudes (15° or less) when the atmosphere is not perfectly clear. Haziness increases refraction. If compelled to take a low altitude when there appears to be more than the normal amount of refraction, correct the refraction for the height of the barometer by Table 21, Bowditch.

New Table 46 gives all corrections (except I. E.) in one.

Example: At sea, June 27, 1917, observed meridian alt.: ⊙ (this sign stands for the sun; * for a star) 67° 26′ 15″; index error, 1° 15′+; height of eye, 25

feet. Required the T. C. A. (true central altitude).

Obs. alt.⊙	67° 26′ 15″
I. E.	1° 15′ 00″
	68° 41′ 15″
Semi-diam	16′
	68° 57′ 15″
H. of E. correction	4′ 54″
	68° 52′ 21″
Refraction	23.6″
T. C. A.	68° 51′ 57.4″

THE CHRONOMETER

The chronometer is simply a finely made and adjusted time-piece placed in a box and swung in gimbals, as a compass is, to prevent it from being injured by the motion of the ship.

The care of a chronometer is not essentially a part of the science of navigation, but in practice the navigator has to use and care for his own chronometers, and the author has, therefore, in the latter part of this book, given some suggestions as to the proper treatment of these instruments.

The purpose of the chronometer aboard ship is to register Greenwich time. English and American navigators reckon their longitude east or west from the Greenwich

meridian, and, as we shall learn further on, the computation of longitude consists in ascertaining the difference between the time at Greenwich and the time at the ship.

The secondary reason for carrying a chronometer is that the astronomical data contained in the *Nautical Almanac* are all given for the Greenwich time. The chronometer shows us how many hours before or after Greenwich noon it is, and thus we are enabled to reduce the data to the time of taking the observation.

It is customary at sea to use a hack watch, set to the time of the chronometer, in taking observations, the chronometer itself never being removed from its place.

Every chronometer gains or loses a little time every day. When in port the instrument is taken to a maker, who regulates it and ascertains its *daily rate* of losing or gaining. On returning it to the owner, the maker furnishes a memorandum stating that on such and such a date the chronometer was so many minutes and seconds faster or slower than Greenwich time, and was losing or gaining so much a day.

The navigator, therefore, must correct

the time shown by his chronometer, by adding or subtracting the *daily rate*. It is obvious that the daily rate must be multiplied by the number of days gone since the memorandum was made, and that if it is a losing rate it must be added, and if a gaining rate, subtracted.

Example: A chronometer showing 2 hrs., 15 min., 27 sec. on Oct. 11, was 3 min., 20 sec. slow of Greenwich time on Oct. 1, and its daily rate is 0.8 sec. losing. What is the correct Greenwich time?

Ans. Oct. 1 to Oct. 11 = 10 days; 0.8×10 = 8.0 sec. loss. On Oct. 11, therefore, the chronom. is 3 min., 20 sec.+8 sec. slow.

Chronom. time.......	2 h.	15 m.	27 s.
Correction +........		3 m.	28 s.
Correct G. T.........	2 h.	18 m.	55 s.

It is obvious that the correction for daily rate may be computed for many days in advance. The navigator must, however, be sure to remember to correct his chronometer time. If he fails to do so, he will fall into serious, perhaps even fatal, errors.

THE NAUTICAL ALMANAC

The *Nautical Almanac* is a book published by the government, and containing certain data, computed by the national astronomers. Without these data the short and simple astronomical problems of navigation cannot be solved.

The navigator must bear in mind at all times the fact that these data are given for Greenwich time. The first series of tables deals with the right ascension of the mean sun or sidereal time at Greenwich. The first tables needed by the student will be those for the sun. They contain the sun's declination and the equation of time for every two hours of each day in the month. A plus sign before a declination means it is north; a minus sign, south. Plus before an equation means it must be added to mean time to get apparent time; minus, it must be subtracted. H. D. in each column means "hourly difference."

The student must not be alarmed by these data. They are much simpler affairs than they appear to be. But he must understand them thoroughly and know how to handle them before proceeding to the simplest observation.

FACSIMILE OF PART OF NAUTICAL ALMANAC

SUN, JANUARY, 1917

G. M. T.	SUN'S DECLINATION		EQUATION OF TIME	
h.	deg.	m.	m.	s.
0	−20	48.0	−10	9.2
2	20	47.0	10	10.8
4	20	46.1	10	12.5
6	20	45.1	10	14.1
8	20	44.1	10	15.8
10	20	43.1	10	17.4
12	20	42.1	10	19.1
14	20	41.1	10	20.7
16	20	40.1	10	22.3
18	20	39.1	10	24.0
20	20	38.1	10	25.6
22	20	37.1	10	27.2
H. D.		0.5		0.8

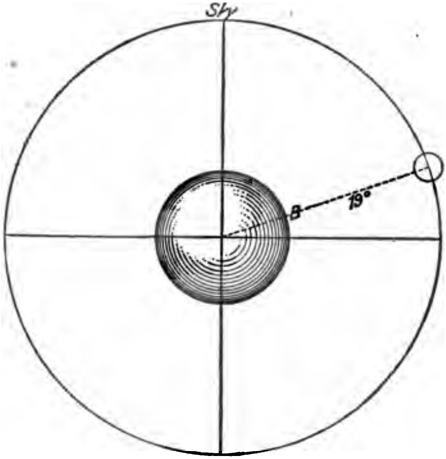


ILLUSTRATION OF DECLINATION

Declination.—The declination of a celestial body is its distance north or south of the equator, measured in degrees. In other words, declination is simply celestial latitude. The sky as it appears to the eye constitutes a sphere surrounding the earth, as in the diagram. The circumference of this sphere must contain 360°. Hence if the sun were immediately over a

point, say B, it would be in lat. 19° N., or, in other words, its declination would be 19° N.

Declination is, however, a varying quantity. Every school-boy knows that the sun goes south in winter and comes north in summer. This is because the axis of the earth is inclined to the plane of its orbit. If it were perpendicular, the sun would always be immediately over the equator.

The extreme limits of the sun's declination are 23° 27′ 30″ north and south. The former point is reached on June 21, and the latter on Dec. 21. Half way between the former and the latter the sun crosses the line, bound south, as the sailors say. Therefore from June 21 to Sept. 22 or 23 the sun is in north declination, which is constantly decreasing. From the latter date till Dec. 21 it is in south declination, which is always increasing. From Dec. 21 till March 21 or 22 the sun's south declination decreases, and from the latter date till June 21 it is in north declination, increasing. These points are extremely important. By remembering them you can never be in doubt as to whether the declination is north or south.

It is obvious that it is important for the navigator to know the rate at which the declination changes. This is found in the N. A. (symbol for *Nautical Almanac*). You can select the declination for every two hours from the monthly tables for the sun. You can compute the intervening hour easily. If the declination at 2 o'clock is 9° 10.6′, and at 4 o'clock 9° 12.5′, at 3 o'clock it must be half the difference, or 9° 11.5′. You can do this also by applying the hourly difference, given in the N. A., making it fractional when you have less than an hour's change to account for. In the case just cited, a half-hour's difference would be .45″.

Note whether the declination is increasing or decreasing. The figures in the almanac will show this. Be careful to apply the hourly difference accordingly.

Note: The time in the N. A. is astronomical, reckoned from 0 (noon of one day) to 0 (noon) of the next.

Example: At sea, May 17, 1917, chronom. showed 10 hrs., 30 min., 12 sec. A.M. Required, the cor. dec. of sun.

Dec. 10 A.M.	. 19° 14.6′ N.	Dec. 10 A.M.	19° 14.6′ N.
Dec. noon . . .	19° 15.7′ N.	Dif. for 30 min.	.2
Diff for 2 hrs.	1.1		19° 14.8′ N.
" " 1 hr.	.5		
" " ½ hr.	.2		

Now let us work one by applying the H. D. given in the N. A. At sea, Jan. 22, 1917, chronom. showed 2 hrs., 45 min., 00 sec. P.M. Required, cor. dec of sun

Dec. 2 P.M.	19° 43.3′ S.	H. D.	.6
	.45′	45′ = .75 hr.	.75
Cor. dec.	19° 42.9′ S.		30
			42
			.450

The tenths of minutes need not always be turned into seconds. Six seconds equals one-tenth of a minute. Hence the above cor. dec. is 19° 42′ 54″ S. But it is customary to do most work in degrees, minutes, and tenths of minutes. The data in the N. A. are generally thus expressed. Where great accuracy is needed, the tenths of minutes can be turned into seconds.

APPARENT AND MEAN TIME—THE EQUATION

Apparent time is that shown by the sun. Mean time is that shown by the clock.

The equation of time is the difference between them.

The earth rotates on its axis once in 24 hours, and theoretically the sun crosses the meridian of any given place at precisely 12 o'clock each day, and it is then noon. As a matter of fact this is not so. The earth does not travel around the sun at a uniform rate of speed, and consequently sometimes the sun is a little ahead of time and again it is behind.

Now you cannot manufacture a clock which will run that way. Its hours must all be of exactly the same length, and it must make noon at precisely 12 o'clock every day. Hence we distinguish clock time from sun time by calling the former mean (or average) time and the latter apparent.

Your chronometer shows G. M. T. (Greenwich mean time).

Your cabin clock should show L. M. T. (Local mean time).

The sun always gives L. A. T. (local apparent time.)

Hence, if you wish to add sun time, as ascertained from an observation, to G. M. T., you must convert the former, L. A. T., into L. M. T. by applying the equation of time.

In some operations you must convert G. M. T. into G. A. T., which is also done by applying the equation.

The equation is given in the N. A. with a sign prefixed, showing whether it is to be added or subtracted. Since the figures given in the time column (col. 1) are for G. M. T., these signs + or − show whether the equation is to be added to or subtracted from G. M. T. to convert it into G. A. T. If you already have ascertained apparent time and wish to convert it into mean time, obviously you must reverse the adding or subtracting process.

The equation is subject, like declination, to hourly variation. This is given at the foot of the column of equations for each day. The equation itself, like the declination, is shown for every two hours of the dav at Greenwich.

The equation should be corrected just as the dec. is, preferably by applying the H. D. as given in the N. A.

Do not forget that the time in N. A. begins at noon. Ten o'clock A.M. of Jan. 17 is 22 o'clock of Jan. 16.

An approximate knowledge of your longitude will enable you to determine whether the chronometer, which is marked up to 12 hrs. like an ordinary clock, indicates A.M. or P.M. time at Greenwich. Turn the long. into time. In west long. your time must be earlier than Greenwich. In east long. *vice versa*. For example, in round figures New York is 5 hrs. west of G. At 3 P.M. in G. it is 10 A.M. in N. Y. In 5 hrs. east long., your clock showing 3 P.M., it is 10 A.M., or 22 hrs. astronomical at G.

LATITUDE BY MERIDIAN ALTITUDE

A meridian altitude is one taken when the celestial body observed bears true south or north of the observer, or is precisely above the meridian of longitude on

which he stands. In the case of the sun this is at apparent noon.

A meridian altitude gives the most accurate latitude, for reasons which will hereafter be explained.

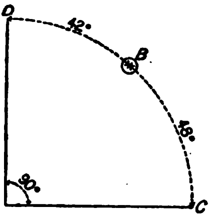
The general formula for a meridian altitude is lat. = zenith distance + or — declination.

Zenith distance is the distance, measured in degrees, from the point precisely over the observer's head to the observed body. Let us suppose that you and the sun are both north of the equator. If now you can ascertain exactly how far you are north of the sun, and how far the sun is north of the equator, you will, by adding the two measurements together, know your latitude.

The declination of the sun, obtained from the N. A. and corrected for chronom. time, as already explained, is the distance of the sun from the equator.

The zenith distance is the difference between the altitude of the sun, taken by the sextant, and 90°. You know that it is 90° from the zenith to the horizon. Hence, having got the altitude of the sun, you have only to subtract it from 90° to find

how far you are from the sun. The arc DBC in the diagram measures 90°. If the sun is at B, it is 48° from C, the horizon, and 42° from D, the zenith.



Now if you are 42° north of the sun, and it is 10° north of the equator, you must be 52° north of the equator, or in lat. 52° N.

That is the first and simplest case. Suppose, however, the sun is in south declination, and you are somewhere in north latitude. In that case your distance north of the equator would naturally be the zenith distance minus the declination, because the zenith distance, altitude, and declination together would make an arc of over 90°, and you can't be over 90° north or south of the equator.

Again, suppose that the sun is in 22° south declination, and you are 10° north of the sun. In that case you would have to subtract the zenith distance from the declination to get your latitude, because the sun's latitude is greater than yours. From

these considerations we deduce the following rule:

Begin to measure the altitude of the sun with the sextant a short time before noon. The altitude will constantly increase till apparent noon, when it will stop and then begin to decrease. You will be able to detect this by bringing down the image of the sun to the horizon in the horizon-glass and carefully watching it. The highest altitude attained is the one you need. At that instant note the chronometer time, and report 8 bells to the captain.

To work out the lat., call the altitude S. if the sun is south of you, N. if north. Correct the altitude for semi-diam., dip, and refraction as already explained. Subtract the true central alt. from 90° to obtain the zenith dist. If the alt. is S., name Z. D. north, or *vice versa*. Correct the declination for the chronom. time as already explained. If Z. D. and dec. are both N. or both S., add them, and the sum will be the lat. N. or S. as indicated. If one is N. and the other S., subtract the less from the greater, and the answer will be the lat. named N. or S. after the greater.

At sea, June 15, 1917. Observed merid. alt. ⊙, lower limb, 71° 15′ 00″ S. Index error, −47′; height of eye, 25 ft.; chronom. 3 hrs., 28 min., 15 sec. P.M.; chronom. slow of G. M. T. 1 min., 50 sec., on June 5. Daily rate, − .5 sec. Required lat. of ship.

Obs. alt. ⊙	71° 15′ 00″ S.	Chronom.	3 h. 28 m. 15 s. P.M.
I. E. + ...	47′ 00″	Correction +	1 m. 55
	70° 28′ 00″		3 h. 30 m. 10 s. P.M.
Semi-diam.	16′ 00″		
	70° 44′ 00″		
Dip	4′ 54″		
	70° 39′ 06″	H. D. Dec.	1″
		Time after 3 h.	.5 h.
Refraction	20″	Correction	.5″
T. C. A.	70° 38′ 46″		
	90° 00′ 00″	Cor. Dec	23° 18′ 48.5″ N.
Z. D.	19° 21′ 14″ N.		
Cor. Dec.	23° 18′ 48″ N.		
Lat.	42° 40′ 02″ N.		

At sea, Sept. 25, 1917. Observed merid. alt. ⊙; lower limb, 50° 3′ 00″ S.; index error, +1° 14′; height of eye, 20 ft.; chronom. 2 hrs., 15 min., 10 sec. P.M.; chronom. slow of G. M. T. on Sept. 20, 1 min., 10 sec., daily rate, −.3 sec. Required lat. of ship.

Obs. alt. ⊙ .	50° 03′ 00″ S.	Chronom. .	2 h. 15 m. 10 s. P.M.
I. E. + ...	1° 14′ 00″	Correction. +	1 m. 11.5 s.
	51° 17′ 00″	G. M. T. .	2 h. 16 m. 21.5 s P.M.
S. D.	16′ 00″		
	51° 33′ 00″	Dec. 2 P.M. .	0° 45′ 48″ S.
H. of E. cor.	4′ 23″	Correction. . +	15″
	51° 28′ 37″	Cor. Dec. . .	46′ 03″ S.
Refraction. .	49″		
T. C. A.	51° 27′ 46″		
	90° 00′ 00″		
Z. D.	38° 32′ 14″ N.		
Cor. Dec. . . .	46′ 03″ S.		
	37° 46′ 11″ N.		

In actual practice the combined corrections (except I. E.) for an observation of the lower limb (or, of a star) are taken from Table 46.

At sea, June 20, 1917. Observed merid. alt. ⊙ 86° 29′ 45″ N. No index error; height of eye, 20 ft.; chronom. 10 hrs., 26 min., 30 sec. A.M.; chronom. fast of G. M. T. on date 3 min., 21 sec. Required lat. of ship.

Obs. alt. . . .	86° 29′ 45″ N.		
Correction. . +	11′ 33″		
		Dec.	23° 26′ 48″ N.
T. C. A.	86° 41′ 18″	Cor.	0″
	90° 00′ 00″		
		Cor. Dec.	23° 26′ 48″ N.
Z. D.	3° 18′ 42″ S.		
Cor. Dec. . . .	23° 26′ 48″ N.		
Lat.	20° 08′ 06″ N.		

In actual sea practice so small a correction as .5″ need not be applied to the dec., because it has no effect on the resulting lat. It might be necessary in establishing a geographical location, such as that of a light. Working to tenths of seconds is also rarely necessary in lat. problems. Lat. is generally expressed simply in degrees and minutes, because at sea it is sufficient to know your position within a mile. The preceding problem, in practice, would be worked thus:

Obs. alt	86° 29¾′ N.
Correction..........	11½′
T. C. A.............	86° 41¼′
	90° 00′
Z. D	3° 18¾′ S.
Dec................	23° 27′ N.
Lat	20° 08¼′ N.

The difference between ¼ minute (15″) and 06″ is of no account at sea. Hence, when the chronom. time after the hour and the variation of the dec. are both small, no correction need be applied to the dec. If either one or the other is large, always apply the error. Many licensed masters *never* apply it. Do not follow any such leaders, or you will some day land on

a rock which you think is six or eight miles north or south of you. When approaching the land carry out your work to fractions; you cannot then be too accurate.

Another popular folly with merchant skippers and yacht captains is to regard the correction to the alt. as a *constant* quantity of 12′+. Instead of adding it to the alt. and then subtracting the sum from 90°, they make a short cut and subtract the 12′ from 90°, getting a constant of 89° 48′, from which they always subtract the alt. They would work the last example thus:

Constant	89° 48′
Obs. alt.	86° 29¾′
Z. D	3° 18¼′
Dec	23° 27′
Lat.	20° 08¾′ N.

That looks short and easy, and the difference is only ½ mile. But let us take another case. On Dec. 20, 1894, your obs. merid. alt. was 11° 34′ 00″ S.; no index error; height of eye, 30 ft.; chronom. 11 hrs., 00′ 00″ A.M.

Right way		Wrong way	
Semi-diam...	16′ 00″+	Constant..	89° 48′
Dip.........	5′ 22″−	Obs. alt...	11° 34′ S.
Refraction...	4′ 36″−	Z. D......	78° 14′ N.
Correction....	6′ 02″+	Dec.......	23° 26¾′ S.
		Lat.......	54° 47¼′

Obs. alt. ☉...	11° 34′ S.
Correction....	6′+
T. C. A......	11° 40′
	90° 00′
Z. D.........	78° 20′ N.
Dec..........	23° 26¾′ S.
Lat..........	54° 53¼′ N.

The student will note that the 89° 48′ puts the latitude 6′ in error; and it fails just at the time when accuracy is most needed—in winter. The cause of the error is the failure to allow for dip and refraction.

LATITUDE BY MERIDIAN ALTITUDE OF A STAR

The student should purchase a set of simple star maps, and acquaint himself with the location of the principal fixed stars. Having learned to know the stars, he should practise assiduously at taking their altitudes. The best hours for observation are morning and evening twilights, when the horizon is clearly defined.

Moonlight nights also bring out a good horizon. With practice and a *first-class sextant*, fitted with a star telescope and well-silvered mirrors, the student will in time learn to "shoot" stars on any clear starlight night.

It is of inestimable value to know how to use the stars. The sun may be overclouded at noon—or all day—and at dusk there may be a star on your meridian to give you the latitude. You can find stars on the meridian at various hours of the night, and, the altitude once secured, the rest is even easier than working out lat. from the sun.

The declinations of all the stars available for the navigator are to be found in the back part of the N. A., in the star tables. Those marked + are N., those − are S. The *annual* variation of declination is so small that the correction is monthly; hence the chronometer time is not taken, and no allowance has to be made for semidiameter. With these exceptions the method of working out the lat. by a star's merid. alt. is the same as that for the sun. You can tell when the star is approaching the meridian by its bearing.

Example: At sea, Dec. 7, 1917. At 10.50 P.M. took merid. alt. * Aldebaran (α Tauris) 75° 21′ 00″ S.; no index error; height of eye, 20 ft.

Obs. alt. *	75° 21′ 00″ S.	
Cor.	4′ 39″	(Table 46)
T. C. A.	75° 16′ 21″	
	90° 00′ 00″	
Z. D.	14° 43′ 39″ N.	
Dec.	16° 20′ 48″ N.	
Lat.	31° 04′ 27″ N.	

Nothing in the shape of a calculation could be much simpler than that. The practical part of the operation can be simplified, however, by knowing one or two additional facts. In the first place, you need to know how to find out what star you can use at a particular hour. For this you must employ the right ascension of the sun and the right ascension of the star required. The meaning of the term right ascension, designated R. A., will be explained later. The R. A. of the sun is to be found on the first pages of the N. A. The R. A. of the star is to be taken from the star table.

Subtract the sun's R. A. from that of the star. If the latter is the smaller, add

24 hours to it. The remainder will be the time of the star's meridian passage.

To know which star will cross the meridian after a certain hour, add that hour to the sun's R. A. The sum will be the R. A. of your own meridian. If it is more than 24 hours, subtract 24 hours from it. The star table will then show you what star's R. A. is equal to or a little greater than your own. That will be the next star to cross your meridian. If you are sailing to the eastward, it will cross a little ahead of time; if you are going west, it will be a little behind.

The next thing to do is to set your sextant at about the altitude the star will attain at its meridian passage, and at the proper time direct your instrument toward the south or north point of the horizon. The image of the star will at once appear in the horizon-glass, and you will have only a few minutes of watching for the merid. alt.

To calculate a merid. alt. subtract your lat. by D. R. from 90°. Call the remainder co-lat., and mark it N. or S. the same as the lat. If the co-lat. and the dec. are of the same name, add them; if of different names, subtract. The result is the approximate merid. alt.

Example: At sea, Aug. 29, 1917. Desired to correct the lat. by D. R. by a star merid. at 9 P.M.

R. A. ☉ . . . . . . 10 h. 28 m. 30 s.
Time at ship . . . 9 h. 00 m. 00 s.

R. A. M. . . . . . . 19 h. 28 m. 30 s.
R. A. Altair. . . . 19 h. 48 m. 06 s.
R. A. ✱. . . . . 19 h. 48 m. 06 s.
R. A. ☉ . . . . 10 h. 28 m. 30 s.

Time of merid. passage. . 9 h. 19 m. 36 s.
Lat. by D. R. . . . . . . 45° 38′ 00″ N.
90° 00′ 00″

Co-lat. . . . . 44° 22′ 00″ N.
Dec. Altair . . . . 8° 39′ 00″ N.

Approx. merid. alt. . 53° 01′ 00″

You will know whether the star is north or south of you by its dec. If you are in north lat., the star will be S. of you if its dec. is S., or if its dec. is north and less than your lat. If its dec. and your lat. are both N., and the former is the greater, the star will be north of you. The same principle applies if you are in S. lat.

Captain Lecky notes that sometimes you can get two stars, one north and one south, almost at the same time. Always take advantage of such a chance, for it lessens the range of error to take the mean of two observations. Suppose one star gave lat. 48° 15′ N., and the other gave 48° 10′ N. The

mean, 48° 12′ 30″ N. would be pretty nearly correct.

LATITUDE BY MERIDIAN ALTITUDE OF A PLANET

The mean time of passing the meridian and the declinations of the planets are given in the N. A. in the latter part. The dec. has to be corrected in the case of a planet, as it changes quite rapidly. The almanac gives the dec. for each day of the month and the variation for each day in tenths of minutes. The remainder of the operation is the same as that for a star.

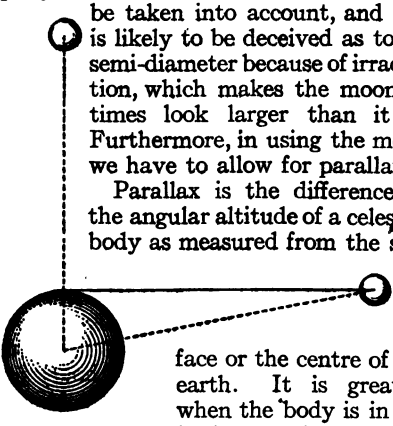
Example: At sea, Feb. 27, 1917. Obs. merid. alt. Saturn, 75° 21′ 00″ S.; no index error; height of eye, 20 ft.; G. M. T., 12 hrs., 5 min., 00 sec. A.M.

Obs. alt. Sat.	75° 21′ 00″
Cor.	4′ 39″
T. C. A.	75° 16′ 21″
	90° 00′ 00″
Z. D.	14° 43′ 39″ N.
Dec.	21° 31′ 54″ N.
Lat.	36° 15′ 33″ N.

Daily change	5′
Time	.5 day
Correction	2.5″
Dec.	21° 31′ 54″ N.
Cor.	negligible

LATITUDE BY MERIDIAN ALTITUDE OF THE MOON

The moon has advantages and disadvantages. The declination changes so rapidly that even minutes of time have to be taken into account, and one is likely to be deceived as to its semi-diameter because of irradiation, which makes the moon at times look larger than it is. Furthermore, in using the moon we have to allow for parallax.



PARALLAX

Parallax is the difference in the angular altitude of a celestial body as measured from the surface or the centre of the earth. It is greatest when the body is in the horizon, and disappears when it is at the zenith. The sun is so far away that its parallax never exceeds 9″. The stars have practically none at all from the earth's surface. The moon, however, is near enough to

make an allowance necessary. On the other hand, it is often visible in daylight and may be used at the same time as the sun to get combined observations (see Sumner method). Also, it lights up the horizon at night, greatly facilitating the navigator's work. Therefore it should be used when helpful, despite the ready liability of the computations to error. The navigator must be especially careful in moon work.

To work a merid. lat. of the moon, find the G. M. T. of moon's merid. passage (transit) in the N. A. under proper date. Apply the correction for long. from Table 11 (Bowditch). Result is the time of local merid. passage. Add or subtract ship's long. to get G. M. T. of local merid. passage. Add longitude correction if your long. is west; subtract, if east. Get dec. of moon for hour (or nearest hour) from N. A. The diff. for every two hours is given at the right in small figures in tenths of minutes. Enter Table IV. of the N. A., applying the number of minutes before or after the hour of G. M. T. local merid. passage at the left, and the two-hour diff. at the top, and obtain number of tenths of

a minute change of dec. in · number of minutes of time over or under the hour. Apply this correction to dec.

With moon's horizontal parallax (obtained from N. A.), enter Table 49 (Bowditch) and find correction for observed alt. This is given for H. of E. 35 ft. Small table gives changes for other heights. Add or subtract as table directs.

With correct alt. and dec. proceed as with merid. sight of sun. (See table on next page.)

MERIDIAN ALTITUDE BELOW THE POLE

It is frequently possible to get an altitude of a star when it is crossing the meridian below the pole. The north pole of the heavens is marked very closely by the polestar, which is never more than 1° 20′ distant from the pole. The stars in the northern part of the heavens apparently revolve around the pole, as may be plainly seen in the case of the constellation known as the "Dipper." When the given star is directly under the pole it is on the meridian, and will give the latitude just as correctly as when directly above it.

July 10, 1916. Long. 80° W. Observed alt. moon's upper limb, 59° 06′ 40″ N. I. E., + 2′. H. of E., 19 ft. Required lat. of ship. (Bowditch).

Obs. alt.	59° 06′ 40″ N.
Corr.	+ 11′ 30″
T. C. A.	59° 18′ 10″ N.
Z. D.	30° 41′ 50″ S.
Dec.	22° 40′ 42″ S.
Lat.	53° 22′ 32″ S.

Table 49	+ 9′ 30″
I. E.	+ 2′ 00″
Cor.	+ 11′ 30″
Hor. Par	59′ 12″
Dec., 12 h.	22° 30.4′ S.
Cor.	+ 10.3
	22° 40.7′ S.

G. M. T. of G. Transit	7h. 40 m.
Cor. for Long. (Table 11)	+ 13 m.
L. M. T. of local transit.	7 h. 53 m.
Long.	+ 5 h. 20 m.
G. M. T. loc. trans.	13 h. 13 m.
H. D. dec.	8.5′
G. M. T.	1.22h.
Cor.	10.3′.

When in very high latitudes, where the sun does not set during six months of the year, the same thing may be done with the sun.

The rule is a simple one. It reads: polar distance + alt. = lat. Polar distance is the distance of a celestial body from the pole. If the pole and the celestial body are in the same kind of lat., either north or south, you can find the P. D. by subtracting the body's declination from 90°. It is 90° from the pole to the equator. If, therefore, the body is 20° north of the equator, it is 70° south of the north pole. But from the south pole it would be 90° + 20° = 110°. But you could not then get an alt. below the pole, because when in that position the body would be below your horizon. If you are in S. lat., you reckon polar distance from the south pole.

In taking an altitude below the pole, bear in mind that the altitudes continually decrease, and that the *lowest* is the merid. alt.

Example: Oct. 2, 1917, obs. alt. α Ursa Majoris (α of the Dipper), 8° 15′ 00″ N., below pole; H. of E., 10 ft.; no I. E.

Obs. alt. ✱...	8° 15′ 00″	Dip.......	3′ 06″
Cor.........	9′ 28″	Ref.......	6′ 22″
T. C. A......	8° 05′ 32″	Cor.......	9′ 28″
P. D........	27° 48′ 24″		
Lat.........	35° 53′ 56″ N.		

Dec............	62° 11′ 36″ N.
	90° 00′ 00″
P. D...........	27° 48′ 24″

USE OF CONSTANT

In the Navy it is the common method to prepare a constant for the computation of the merid. alt. By application of the observed alt. the lat. is immediately known and may be signalled to a consort or flagship without delay. The method is simple.

The noon longitude must be well enough known in advance to enable the navigator to correct the declination. The noon altitude must be computed according to the formula given in the last paragraph of page 108. For a meridian alt. below the pole subtract the polar distance from lat. by D. R. We now have four possible cases:

I.—Lat. and dec. same name, lat. greater: formula,

$+90° + \text{Dec.} - \text{Cor.} - \text{Obs. alt.}$

II.—Lat. and dec. same name, dec. greater:

$-90° + \text{Dec.} + \text{Cor.} + \text{Obs. alt.}$

III.—Lat. and dec. opposite names:

$+90° - \text{Dec.} - \text{Cor.} - \text{Obs. alt.}$

IV.—Lat. and dec. same name, alt. below pole:

$+90° - \text{Dec.} + \text{Cor.} + \text{Obs. alt.}$

The correction in each formula is that taken from Table 46 for the computed alt.

In the case of the first example of merid. alt. (p. 101) the work with constant would be thus:

Correction, +10′ 46″. I. E. – 47′. Total – 36′ 14″. Since the correction is minus in the formula, the sign, being minus, must be changed to +36′ 14″.

	+ 90° 00′ 00″
Dec................	+ 23° 19′ 00″
Cor................	+ 36′ 14″
Const..............	113° 55′ 14″
Alt................	— 71° 15′ 00″
Lat................	42° 40′ 14″ N.

LATITUDE BY EX-MERIDIAN ALTITUDE OF THE SUN

Before proceeding further the student should learn how to convert longitude into time and time into longitude. The former operation will enter into most of the calculations yet to come, and the latter is always part of longitude workings.

The conversion is based on the fact that the sun takes 24 hours to pass around the 360° of the earth's circumference. Divide 360 by 24 and you get the number of degrees he passes in one hour, viz., 15°. Hence 15° of long. = 1 hour, and 1° = $\frac{1}{15}$ of 1 hour, or 4 minutes. Furthermore, 15′ of long. = 1 minute of time, and 1′ of long. = $\frac{1}{15}$ of 1 minute of time, or 4 seconds. Table 7, Bowditch, gives the various equalizations up to 360°, but you should be able to do without it.

To convert time into long.—Multiply the hours by 15 to get degrees. Divide the minutes by 4, and add the quotient to the number of degrees. If any minutes are left over, multiply them by 15. Divide the seconds by 4, and add the quotient to the minutes. Finally multiply the remaining seconds by 15.

Example: Turn 4 hrs., 29 min., 38 sec. into long.

$$\begin{array}{r} 4 \\ \underline{15} \\ 60 \\ \underline{7} \\ 67^{\circ} \end{array} \qquad \begin{array}{l} 4)29(7^{\circ} \\ \;\;\;\underline{28} \\ \;\;\;\;1 \times 15 = 15' \\ \qquad\qquad\;\;\; \underline{9} \\ \qquad\qquad\;\; 24' \end{array} \qquad \begin{array}{l} 4)38(9' \\ \;\;\;\underline{36} \\ \;\;\;\;2 \times 15 = 30'' \end{array}$$

Ans. 67° 24′ 30″.

To convert long. into time.—Multiply each member of the quantity by 4 and divide by 60, adding any figures left over to the result.

Example: Turn 50° 40′ 15″ into time.

$$\begin{array}{l} \quad\;\; 50^{\circ} \\ \qquad\;\; 4 \quad \text{h.} \\ 60)\overline{200}(\;3 \\ \quad\;\; \underline{180} \\ \quad\;\;\; 20\text{ m.} \end{array} \qquad \begin{array}{l} \quad\;\; 40' \\ \qquad\;\; 4 \quad \text{m.} \qquad \text{m.} \\ 60)\overline{160}(2 + 20 = 22 \\ \quad\;\; \underline{120} \\ \quad\;\;\; 40\text{ s.} \end{array} \qquad \begin{array}{l} \quad\;\; 15'' \\ \qquad\;\; 4 \quad \text{s.} \qquad \text{s.} \\ 60)\overline{60}(1 + 40 = 41 \\ \quad\;\; \underline{60} \\ \quad\;\;\; 00 \end{array}$$

Ans. 3 hrs., 22 min., 41 sec.

It is from this convertibility of time into degrees and parts of degrees (and *vice versa*) that we get the expression hour-angle.

Hour-angle is the distance of a body east or west of the observer's meridian, expressed either in time or angle. Thus at 11 A.M. the sun's hour-angle is either 1 hour or 15° E.; at 1.15 P.M. it is either 1 hour and 15 min. or 18° 45′ W.

Now we come to ex-meridian altitudes. Suppose that at 12 o'clock, apparent time, the sun is obscured by clouds, and you cannot get your meridian altitude, but five minutes later it is perfectly clear. It is possible, fortunately, to use it even then. In fact, you may work the ex-meridian problem from 26 minutes before till 26 minutes after noon, but you must know your longitude accurately.

If you know the longitude, you can compute the hour-angle, and if you know that, you can reduce the altitude to what it would be at noon by applying the rule that near the meridian the altitude varies as the square of the interval from noon. Table 26, Bowditch, gives the change of altitude in 1 minute, and Table 27 gives the squares of the intervals up to 13 minutes. If you know the interval, or hour-angle, all you have to do is to multiply the change for 1 minute by its square, and add the result to your T. C. A., which, either before or after precise noon, must be just that much too low. Hence we get this rule:

Take the chronom. time of the observation. Correct it for rate, as usual. Correct the chronom. time for long, by sub-

tracting from it your long. expressed in time if long. is W., and adding if long. is E. Result is local mean time. Convert this into local apparent time by applying the corrected equation of time, as already explained. If the L. A. T. is more than 12 hours, the surplusage is the hour-angle west. If less, subtract it from 12 hours, and the remainder is the hour-angle east. Enter Table 26 with the dec. of the sun at the top, and the lat. by D. R. at the side, and take out the change of alt. for 1 minute. Enter Table 27 with the hour-angle at the top and the change of alt. at the side. Pick out the corresponding reduction to the merid., selecting units and tenths separately and adding them. Add this to the T. C. A. to obtain the merid. alt. Subtract this from 90° to get Z. D., and apply the dec. to get the lat. as heretofore directed.

Example: At sea, July 11, 1917. Lat. by D. R. 50° 01′ 00″ N., long. 40° W. Obs. ex-merid. alt. ⊙ 61° 45′ 30″. H. of E., 15 ft.; I. E., 4′ –. Chronom. time (corrected) 2 hrs., 38 min., 00 sec. P.M.

G. M. T. . .	2 h. 38 m. 00 s. P.M.	
Long. W. . .	2 h. 40 m. 00 s. P.M.	
L. M. T. . .	11 h. 58 m. 00 s. A.M.	
Cor. equat.	5 m. 13 s.	
L. A. T. . . .	11 h. 52 m. 47 s. A.M.	
	12 h. 00 m. 00 s.	
H. A.	7 m. 13 s. E.	

Table 26, variation of alt. . . . . 2.5"

Table 26	Table 27
2"	1' 45"
.5"	25"
	2' 10"

Obs. alt.	61° 45' 30"
Cor.	7' 41"
T. C. A.	61° 53' 11"
Cor.	2' 10"
Merid. alt.	62° 55' 21"
	90° 00' 00"
Z. D.	27° 04' 39" N.
Dec.	22° 09' 00" N.
Lat.	49° 13' 39" N.

"PHI PRIME" SIGHT

With a celestial body whose bearing is not over 45° from the meridian, whose dec. is not less than 3°, and which is within 3 hrs. of merid. passage, the ϕ' and ϕ'' formula can be used. Table 44 is employed (also in longitude sights) and must be understood thoroughly before going further.

Table 44 contains the logarithmic sines, cosines, tangents, cotangents, secants, and cosecants for all angles up to 180°. If you have studied trigonometry, you will know what these terms mean. If you have not, you can use them just as well for the purposes of navigation. The top and bottom of a page of Table 44 look like the table on page 124.

If the desired number of degrees be found at the top, the name, sine, cosine, etc., must also be found there, as in the cases of 18° and 161° in the example. If the number of degrees is at the bottom, the logarithmic name will be found there. The additional minutes must be found in the column M, read down when the degrees are at the top, and up when at the bottom. In applying the seconds of your angle choose the logarithm for the nearest minute. Thus, for logarithms of 10° 15′ 42″ go to 10° 16′.

The columns marked Hour A.M. and Hour P.M. contain the apparent time corresponding to the sines, cosines, etc. When you come to longitude, you will have to take out the time corresponding to sines. When the observation is taken before

18°			A		A	B		B	C		C	161°
M.	H. A.M.	H. P.M.	Sine	Diff.	Cosecant	Tangent	Diff.	Cotangent	Secant	Diff.	Cosine	M.
0	9 36 00	2 24 00	9.48998	0	10.51002	9.51178	0	10.48822	10.02179	0	9.97821	60
1	9 35 52	24 8	.49037	1	.50963	.51221	1	.48779	.02183	0	.97817	59
2	35 44	24 16	.49076	1	.50924	.51264	1	.48736	.02188	0	.97812	58
3	35 26	24 32	.49115	2	.50885	.51306	2	.48694	.02192	0	.97808	57
59	9 28 8	2 31 52	9.51227	37	10.48773	9.53656	41	10.46344	10.02429	4	9.97571	1
60	28 00	32 00	.51264	38	.48736	.53697	42	.46303	.02433	4	.97567	0
M.	H. P.M.	H. A.M.	Cosine	Diff.	Secant	Cotang't	Diff.	Tangent	Cosecant	Diff.	Sine	M.
108°			A		A	B		B	C		C	71°

Seconds of time......		1 s.	2 s.	3 s.	4 s.	5 s.	6 s.	7 s.
Prop. parts of col.	A	5	9	14	19	24	28	33
	B	5	10	16	21	26	31	37
	C	1	1	2	2	3	3	4

noon, you take the time out of the A.M. column; afternoon, from the P.M. Notice that they are reversed at the bottom of the page. This means that if your sine is in the column having the word "sine" at the top, you work from the top of the page down; if your sine is in the column with "sine" at the bottom, you read from the bottom of the page up.

The parts of the sines, etc., to the left of the decimal mark are called the indexes. If the index is 10, omit it in adding the figures. Thus, if you were required to add the secant of 18° 03′ to the cosine of 71°, you would have 10.02192 + 9.51264 = 9.53456. To simplify calculations, omit the index 10 when taking out the logarithm in the first place.

The use of the proportional parts of the columns A, B, and C may be omitted until we come to chronometer sights. We are now ready to give the rule for the ϕ' and ϕ'' sight.

Take the chronometer time of the observation, and compute the hour-angle of the sun as already explained. Convert the hour-angle to terms of degrees, minutes, and seconds. Add the secant of the hour-

angle to the tangent of the corrected declination, and the sum will be the tangent of an arc, which take out and call it ϕ''. Add the sine of the arc ϕ'' to the cosecant of the corrected dec. and the sine of the T. C. A. The sum will be the cosine of an arc to be taken out and marked ϕ'. Mark ϕ'' N. or S. as your dec. is; mark ϕ' N. or S. as your Z. D. is. Like names, add; different names, subtract. Answer is lat. at time of observation (not noon).

Example: At sea, June 8, 1917. Position by D. R., lat. 27° 40′ N., long. 60° 15′ W. Obs. alt. of sun's lower limb, after noon, 78° 30′ 00″. G. M. T., 4 hrs., 44 min., 30 sec. P.M.; H. of E., 20 ft.

This method shown in the table on page 127 is of exceptional utility, as it can be employed at intervals much removed from noon, at times admits of an observation available for both lat. and long., and is applicable to any celestial body.

LATITUDE BY THE POLESTAR

Before attacking the method of computing lat. by Polaris, the north star, the student may as well learn several more astro-

G. M. T.	4 h. 44 m. 30 s.
Long. W.	4 h. 01 m. 00 s.
L. M. T.	43 m. 30 s.
Equation	1 m. 14 s.
	44 m. 44 s. = 11° 11′

H. A.	11° 11′ 00″	sec.	.00833		
Dec.	22° 50′ 24″ N.	tang.	9.62433	cosec.	.41111
Alt.	78° 41′ 27″			sin.	9.99147
ϕ''	23° 14′ 00″ N.	tang.	9.63266	sin.	9.59602
ϕ'	4° 36′ 00″ N.			cosine	9.99860
Lat.	27° 50′ 00″ N.				

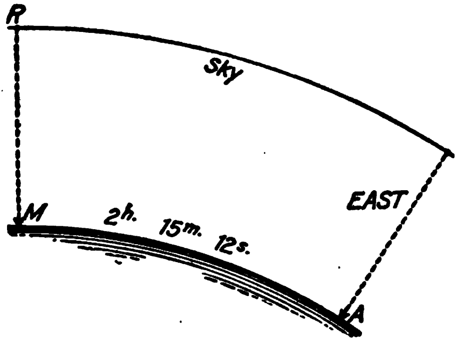
nomical facts, some of which demand close study for their comprehension. He has learned the difference between mean and apparent time. He must now learn what astronomical time and right ascension are, and he may as well complete the list with sidereal time.

Astronomical time is reckoned from noon of one day to noon of the next, and hence the astronomical day corresponds to the 24 hours of a ship's run. The hours are counted from 1 to 24, so that 4 o'clock in the morning of Oct. 5 is astronomically 16 o'clock of Oct. 4.

Right ascension is practically celestial longitude. A place on the earth is located by its latitude and longitude; a heavenly body by its declination and right ascension. But R. A., as it is indicated, is not measured in degrees and minutes, nor is it measured east and west. It is reckoned in hours and minutes all the way around the sky from west to east through 24 hours.

The celestial meridian from which this celestial longitude begins is not that of Greenwich, but it is that passing through the equator at the point where the sun crosses the line in the spring.

When we speak of a star as having a R. A. of 3 hrs., 42 min., 15 sec., we mean that any given spot on the surface of the earth will occupy 3 hrs., 42 min., 15 sec. in revolving from the prime meridian of celestial long. to the meridian of the star.



You will meet with the expression right ascension of the meridian. That means the R. A. of the meridian on which you are, and in many stellar observations you need to know it in order to compare it with the R. A. of the star.

It so happens that the R. A. of the meridian and local sidereal time are the

same thing. Sidereal time is "star" time, as opposed to solar or "sun" time. The sidereal day contains 24 hours, but it does not begin at midnight as the legal day does, nor at noon like the astronomical day. It begins when the prime celestial meridian (that at which celestial longitude commences) is right over the meridian on which you stand. It is then what you might call sidereal noon at your place, just as it is solar noon when the sun is on the meridian.

Now suppose R. to be the prime celestial meridian, and M. your meridian. When M. is under R., sidereal time at M. begins. Also right ascension is measured eastward in hours and minutes from R. Now if M. occupies 2 hrs., 15 min., 12 sec. in revolving with the motion of the earth to A, when it arrives at A it will be 2 hrs., 15 min., 12 sec. o'clock sidereal time at M. And that must also be the R. A. of M., because R. A. is measured from the same point as sidereal time.

At present the student needs to learn only two things: first, how to find the sidereal time at Greenwich corresponding to any given hour of mean time there, and

secondly, how to find the sidereal time corresponding to any given hour at his own meridian. It is obvious that if you can find the former, you can easily get the latter by applying the longitude of your meridian (converted into time).

A sidereal day measures in mean time—that is, by a chronometer or ordinary clock—23 hrs., 56 min., 04 sec. In other words, every hour, minute, and second in a sidereal day is a little shorter than its counterpart in a solar day. So, in turning mean time into sidereal time, we have to make some allowances. Table 8, Bowditch, gives the allowances for changing sidereal to mean time, and Table 9 for changing mean to sidereal. Similar tables are to be found in the N. A.

The N. A. will give you the sidereal time at Greenwich noon for every day in the year (right ascension of mean sun, pages 2 and 3). Right ascension of the mean sun is the sidereal time at Greenwich when the mean time clock shows noon. Convert G. M. T. into Greenwich sidereal time (G. S. T.) thus:

Add to G. M. T. the G. S. T. for the preceding noon, and the allowances given in

Table 9, for the number of hours, minutes, and seconds in the G. M. T. If the sum is more than 24 hours, subtract 24 hours from it, because at the end of 24 hours Sid. T. begins over again.

Example: Required G. S. T., Nov. 2, 1917, when the G. M. T. by chronom. (corrected) was 7 hrs., 25 min., 15 sec.

G. M. T.	7 h. 25 m. 15 s.
Sid. T. at G. at preceding noon	14 h. 44 m. 45 s.
From table 7 hrs. 25 m.*	1 m. 13 s.
Sid T. at G.	22 h. 11 m. 13 s.

Rule for finding S. T. at ship or R. A. M., when longitude is known: Find the mean time at ship by applying the longitude to the G. M. T. as previously explained. Add to mean time at ship the G. S. T. for the preceding noon and the allowances for the G. M. T. from Table 8. If the result is over 24 hours, subtract 24 hours from it.

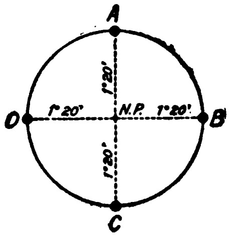
Example: Required the S. T. at ship Aug. 19, 1917, when the G. M. T. was 11 hrs., 15 min., 20 sec. P.M. Long. 60° 15′ W.

* The 15 seconds of G. M. T. are disregarded because the allowance is only .041″.

G. M. T.	11 h. 15 m. 20 s.	
Long. W.	4 h. 01 m. 00 s.	
M. T. at ship.	7 h. 14 m. 20 s.	
Sid. T. for preceding noon.	9 h. 49 m. 03.5 s.	
Allow. for 11 h. 15 m.	1 m. 50.8 s.	
Sid. T. at ship.	17 h. 05 m. 14.3 s.	or Rt. Ascension of Meridian.

All this is necessary here, because in order to work the lat. by the polestar you must use the R. A. M. In north latitudes the polestar is available at any hour of the night. This is because it apparently revolves around the north pole of the heavens at a distance of only 1° 20′, making the change of altitude so slow that it can be used always. Of course the star does not revolve around the pole at all. It is the earth that revolves. The student will remember what has been said about hour-angle. Now it is obvious that the H. A. of Polaris may be very great without any serious change in the altitude. Let the centre of the circle page 134 be the north pole of the heavens, and the circumference the apparent orbit of Polaris. At D and B the altitude of the star equals the altitude of the pole, which equals the lat. For the north pole, being 90° from the equator, will be in the horizon of an observer at

the equator. If you go 10° north of the equator, your northerly horizon will drop by 10°, and hence the pole will be 10° high, and so on up to 90°, when the pole would be overhead, or 90° high. With the polestar at A you would have to subtract 1° 20′ from its altitude to get the altitude of the pole, which equals the lat.; at C you would have to add 1° 20′.



Now as the R. A. of M. advances from 0 to 24 hours in exactly the same time as the polestar appears to revolve around the pole, the astronomers have made a table for us by which we can make the proper addition or subtraction to the altitude of Polaris at any hour. What you have to do is to find the sidereal time at the ship or right ascension of the (local) meridian. Hence this is the rule:

Take the alt. and note the chronom. time at instant of observation. Correct the alt. as usual. Find the sidereal time at ship as already explained. With the local

Obs. alt.	40° 27′ 00″
Alt. cor.	5′ 31″
T. C. A.	40° 21′ 29″
Cor. Table I.	1° 05′ 12″
Lat.	39° 16′ 17″ N.

G. M. T.	11 h. 30 m. 00 s. P.M.
Long. W.	3 h. 01 m. 00 s.
M. T. at ship	8 h. 29 m. 00 s.
Sid. T. noon Dec. 20	17 h. 53 m. 59.7 s.
Allow. for 11 h. 30 m.	11 m. 53.3 s.
	26 h. 34 m. 53 s.
	24 h. 00 m. 00 s.
Sid. T. at ship	2 h. 34 m. 53 s.

sidereal time enter Table I., in the back part of the N. A., applying the hours at the top of the column and the minutes at the side. You will thus obtain a correction which, according to sign prefixed to it, is to be applied to the observed altitude of Polaris. The result will be the approximate latitude. The problem is not regarded as giving a latitude as exact as that obtained from a star's meridian passage.

Example: At sea, Dec. 20, 1917. Long. 45° 15′ W.; obs. alt. of Polaris, 40° 27′ 00″; no I. E.; H. of E., 20 ft.; G. M. T., 11 hrs., 30 min., 00 sec. P.M. (See table on page 135.)

The chief difficulty in using Polaris, the student will find, is getting the altitude. The star is very small, and the northern part of the sea horizon not well illuminated; but it can be done after practice, and the star is always useful as a check on other observations.

It is now possible to explain how to work a ϕ' and ϕ'' with a star or planet. You must find the hour-angle of the star, and that is always the difference between the R. A. of the star and the R. A. of your me-

ridian. You will understand this at once if you have fully comprehended what R. A. is. And you will also understand that if the star's R. A. is less than yours, its H. A. is west; and if it is greater than yours, the H. A. is east. Always subtract the less from the greater, and mark the H. A. east or west according to this rule. You will need this point again in star time azimuths, to be explained presently.

How to find the R. A. M. has already been explained. The star's R. A. is got from the star table in the N. A. Having the H. A., proceed as in a ϕ' and ϕ'' sight of the sun.

Example: At sea, June 6, 1917. Obs. alt. of star Altair, 50° 17′ 00″; no I. E.; H. of E., 22 ft.; G. M. T., 4 hrs., 38 min., 09 sec. A.M. = 16 hrs., 38 min., 09 sec., astronom. time. Long. 23° 22′ W. Required lat. of ship.

G. M. T.	16 h. 38 m. 09 s.	Obs. alt..50° 17′ 00″
Long. W........	1 h. 33 m. 28 s.	Cor..... − 5′ 25″
L. M. T.........	15 h. 04 m. 41 s.	T. C. A. 50° 11′ 35″
G. Sid. T. preceding noon.........	4 h. 57 m. 18 s.	
Cor. Table N. A..	2 m. 44 s.	
R. A. M.........	20 h. 04 m. 43 s.	
R. A. Altair.....	19 h. 47 m. 06 s.	
H. A. of Altair.....	17 m. 37 s. = 4° 24′	

H. A.	4° 22′ 00″	sec. . . .00128	
Dec.	8° 38′ 54″	tang. 9.18221	cosec. . . .82276
T. C. A.	50° 11′ 35″		sin. . . . 9.88552
φ″	8° 40′ 00″ N.	tang. . 9.18349	sin. . . . 9.17807
φ′	39° 40′ 00″ N.		cosine. . 9.88635
Lat.	48° 20′ 00″ N.		

COMPASS ERROR BY AZIMUTHS

It is possible now to give the student further directions about finding the compass error by azimuths. The method was introduced under the head of "How to Find the Deviation." The student will see now that in employing the sun what he first requires is the sun's H. A. Hence, in taking an azimuth by the sun, the longitude being known, proceed thus:

Note the time of the azimuth by the chronom. Correct for rate. The result is G. M. T. Convert it into G. App. T. by applying the corrected equation. Convert G. A. T. into A. T. at ship by applying the longitude in time, subtracting it when west, adding it when east. The result is the A. T. at ship. Find H. A. (see page 121), enter the azimuth tables with this and the corrected dec. to get the sun's true bearing.

To take an azimuth by the moon, a planet, or a star.—Note the time by chronom. Apply long. to get M. T. at ship. Proceed to find H. A. of the celestial body as on page 137. With this H. A. and the dec. get the true bearing from the azimuth tables.

RELATIONS OF RIGHT ASCENSION AND HOUR-ANGLE

ERRATA

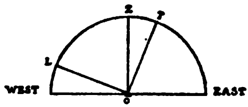
On page 139, the diagram should be described as H. A. West; and on page 140, it should be described as H. A. East.

LT = R. A. of star.
LZ = R. A. of meridian.
TZ = H. A. of star.

The H. A. being west, the formulæ are:

LT = LZ − TZ (R. A. star = R. A. M. − H. A. star)
LZ = LT + TZ (R. A. M. = R. A. star + H. A. star)
TZ = LZ − LT (H. A. star = R. A. M. − R. A. star)

H. A. West



The H. A. being east, the formulæ:

LT = LZ + TZ	(R. A. star = R. A. M. + H. A. star)
LZ = LT − TZ	(R. A. M. = R. A. star − H. A. star)
TZ = LT − LZ	(H. A. star = R. A. star − R. A. M.

LONGITUDE BY CHRONOMETER (OR TIME) SIGHT

The foregoing methods of obtaining the lat. by observation are all that are of practical value at sea. The double-altitudes method is available in no instance where Sumner's problem (yet to come) is not better, and Lecky's ex-meridians below the pole are very rarely of value. Hence we now come to the matter of longitude.

Since the sun revolves (apparently) around the earth once in 24 hours, passing through 15° of long. every hour, if we can ascertain how many hours and minutes east or west of Greenwich the sun is, and how many hours and minutes east or west of the sun we are, we shall know our long.

When the long. is not known, then the problem is to find the local H. A. of the sun.

The H. A. from Greenwich we carry with us in the shape of the chronom., which tells us G. M. T., and that, of course, reveals the H. A. of the sun there. If we find the H. A. here—at our meridian—the difference between the two will be the number of hours, minutes, and seconds we are east or west of the Greenwich meridian, and this quantity is, as we have seen, convertible into the degrees, minutes, and seconds of longitude.

The computation of the H. A. of the sun is a complicated problem in spherical trigonometry; but the navigator has only to know how to use the tables prepared by the astronomers and to employ simple arithmetic.

The necessary data are the T. C. A., the polar distance, and the latitude. At the instant of getting the altitude with the sextant, note the chronom. time accurately and correct it for rate. Make the corrections for dec. and equation of time according to the G. M. T. Then convert G. M. T. into G. App. T. by applying the corrected equation

as directed by the N. A. You need G. App. T. because from your observation of the sun you get L. App. T. If you prefer, you can wait till you have computed that, and then convert it into L. M. T. so as to compare it with G. M. T. The first way is a little more convenient.

If you are in N. lat. and the dec. is N., or in S. lat. and the dec. is S., subtract the corrected dec. from 90° to get the polar distance. If you are in N. lat. and dec. is S., or in S. lat. and dec. is N., add dec. to 90° to get P. D. The rule for the rest of the operation is thus:

Add together the P. D., the lat., and the T. C. A. Divide the sum by 2, and call the quotient the half-sum. From the half-sum subtract the T. C. A., and call the answer the difference. Now add the cosecant of the P. D., the secant of the lat., the cosine of the half-sum, and the sine of the difference, obtained from Table 44. If the index of the sum is more than 9 (say 18), set it down so. Divide this sum by 2. The quotient is the sine of apparent time at the ship, which you are to take out of the A.M. column of Table 44 if the observation was an A.M. one, from the P.M.

column if P.M. The difference between the App. T. at ship and G. App. T. is the long. of the ship in time, which turn into degrees, minutes, and seconds. If G. App. T. is greater than App. T. at ship, long. is west; if less, long. is east. Or, in the memorizing rhyme:

Greenwich time best,
Longitude west;
Greenwich time least,
Longitude east.

Example 1: At sea, Oct. 1, 1917. A.M. obs. alt. ⊙ 17° 15′ 00″; G. M. T., 11 hrs., 30 min. A.M.; lat. 40° 30′ N.; H. of E., 15 ft.; I. E. −3′. (See table on p. 144.)

Example 2: At sea, Oct. 1, 1917. P.M. obs. alt. ⊙ 20° 15′ 00″; G. M. T., 1 hr., 15 min. P.M.; lat. 40° 30′ S.; H. of E., 15 ft. (See table on page 145.)

The student must now learn how to use the proportional parts of the columns A, B, and C in Table 44. In working long. you must be careful about the seconds, because 4 sec. of time = 1′ of long. Hence we proceed thus: Take the difference between the sine of App. T. and the sine nearest to it in the table. Apply the dif-

G. M. T.	11 h. 30 m. 00 s.	Equation. . . .	10 m. 12 s.
Cor. equat. .	+ 10 m. 11.6 s.	Correction. . .	− .4 s.
G. A. T.	11 h. 40 m. 11.6 s.		10 m. 11.6 s.
		Dec.	3° 04′ 06″ S.
Obs. alt.	17° 15′ 00″	Cor.	30″
Correction. . .	+ 6′ 13″		90° 00′ 00″
T. C. A.	17° 21′ 13″	P. D.	93° 04′ 24″

P. D.	93° 04′ 24″	cosec.	.00102
Lat.	40° 30′ 00″	sec.	.11895
Alt.	17° 21′ 13″		
	2)150° 55′ 37″		
½-sum.	75° 27′ 48″	cos.	9.39958
Diff.	58° 06′ 35″	sin.	9.92897
			2)19.44852
			9.72426 = 7 h. 44 m. 02 s. A. T. S.
			11 h. 40 m. 11 s. G. A. T.

Long. 59° 02′ 15″ W. = 3 h. 56 m. 09 s.

G. M. T.	1 h. 15 m. 00 s. P.M.	Equat. 2 P.M.	10 m. 13.7 s.
Cor. equat.	10 m. 13 s.	Correction	.6 s.
G. A. T.	1 h. 25 m. 13 s. P.M.	Cor. equat.	10 m. 13.1 s.

		Dec., 2 P.M.	3° 06′ 00″ S.
Obs. alt.	20° 15′ 00″	Correction	00.7″
Correction	+ 9′ 43″	Cor. dec.	3° 05′ 59.3″ S.
			90° 00′ 00″
T. C. A.	20° 24′ 43″	P. D.	86° 54′ 00.7″

P. D.	86° 54′ 00″	cosec.	.00064
Lat.	40° 30′ 00″	sec.	.11895
T. C. A.	20° 24′ 43″		
	2)147° 48′ 43″		
½-sum	73° 54′ 21″	cos.	9.44297
Diff.	53° 29′ 38″	sin.	9.90518
			2)19.46774
		sin.	9.73387

= 4 h. 22 m. 28 s. P.M. A. T. S.
1 h. 25 m. 13 s. G. A. T.

Long. 44° 18′ 45″ E. = 2 h. 57 m. 15 s.

ference in the little table at the bottom of the page opposite the letter of the column from which the sine was taken. Above this will be found the number of seconds which must be added to or subtracted from the time given in the A.M. or P.M. column. If the sine of A. T. is larger than the sine in the table, add the difference obtained from the little table to the given time; otherwise subtract it.

Example: Obtained sine of App. T. at ship, 9.73387. Difference between this and nearest sine in table, 9. Nearest sine being found in col. A, apply 9 in proportional parts of col. A, at bottom of page. Above 10 (nearest) find 4 sec. Take 4 sec. from the time given for sine 9.73396, and you get the correct time for sine 9.73387, which is (P.M.) 4 hrs., 22 min., 28 sec.

REMARKS ON LONGITUDE

As the lat. is best obtained when the sun bears north or south, so the long. is most accurately found with the sun due east or west. This, however, you can rarely get, for to have the sun due east or west of you, your lat. and the dec. of the sun must be the same. If the sun rose

due east every day and travelled across the sky due west, long. would be got just like lat. You know that it is just 90° from the horizon to the zenith, and you know that 90° is just a quarter of a circle. Now suppose the sun to be due east of you when its alt. was 70°. By subtracting the alt. from 90° you would know that the sun had just 20° to pass through before crossing your meridian. In other words, its H. A. would be 20°, which = 1 hr., 20 min., and hence your App. T. would be 10 hrs., 40 min. A.M.

When the sun is due east or west of you it is said to be in the prime vertical (P. V.). But as the sun's dec. is almost invariably more or less than your lat., your observations for long. are nearly all ex-prime vertical. The farther away from the prime vertical the sun is, the more accurately you need to know your lat., while if the sun is on the P. V., an error of half a degree in the lat. will make no serious difference in the long. How valuable, then, are the stars, from which you can almost always select one which is nearly on the P. V., if not exactly so. In the North Atlantic in winter, when the sun is 20 odd

degrees below the equator, far away from the P. V., the sky is full of bright stars whose declinations bring them well up towards the P. V.

The employment of stars in long. will be explained in the proper place. The point to be urged here is this: Try to get the sun when it bears most nearly east or west of you. To ascertain at what time it will be so enter the azimuth tables with your lat. and the sun's dec. The tables give the true bearing of the sun for every 10 minutes of the day, and you can select the bearing which is nearest to E. or W., and take your observation at the time indicated. Do not fall into the common habit of the merchant marine of always taking the long. at the same hour. Select the right time and get good results.

LONGITUDE BY SUNRISE AND SUNSET SIGHTS

The chronometer sight is the standard method. Sometimes, however, it is cloudy all day and the sun appears just at setting. The rule for sunrise or sunset sights is as follows:

Note the chronom. time when the sun's

upper or lower limb touches the horizon. Correct the chronom. for rate. Correct the dec. as usual, and find the polar distance. Add the lat. and P. D., and from the sum subtract 21′ if the lower limb was observed, or 53′ if the upper limb. Divide the answer by 2 to obtain the "half-sum," and add the 21 or 53 previously subtracted to obtain the "diff." Then proceed as in a chronom. sight, adding the cosec. of the P. D., sec. of the lat., cosine of the half-sum, and sine of the diff., and taking out App. T. at ship to compare with App. T. at Greenwich.

Example: Aug. 16, 1917. Lat. 48° 10′ N. Lower limb ☉ touched horizon at 8 hrs., 30 min., 15 sec., by chronom., slow of G. M. T. 1 min., 15 sec. (See table on next page.)

This method is not often of value and should be employed only when there is no chance of getting a chronometer sight of the sun or some other celestial body.

CHRONOMETER SIGHT OF A STAR

The problem is to find the sidereal time at the ship, and compare it with the sidereal time at Greenwich. As there are 24 hours in a sidereal day, each hour equals

G. M. T.	8 h. 31 m. 30 s.		
Cor. equat.	4 m. 09 s.		
G. A. T.	8 h. 27 m. 21 s.		
Cor. dec.	13° 44′ 18″ N.		
	90° 00′ 00″		
P. D.	76° 15′ 42″	cosec.	.01260
Lat.	48° 10′ 00″	sec.	.17590
	124° 25′ 42″		
	21′ 00″		
	2)124° 04′ 42″		
½-sum	62° 02′ 21″	cos.	9.67113
	21′		
Diff.	62° 23′ 21″	sin.	9.94747
			2)19.80710
			9.90355 = 7 h. 05 m. 42 s. A. T. S.
			8 h. 27 m. 21 s. G. A. T.
		Long. 20° 24′ 45″ W.	= 1 h. 21 m. 39 s.

15° of longitude, as in solar time. Hence long. can be obtained as well from sidereal as from solar time. The rule is as follows:

Take the altitude and note the chronom. time as usual. Convert G. M. T. into G. Sid. T. as already explained. Find the hour-angle of the star by the use of the P. D., lat., and alt. in exactly the same way as for the sun—only *always* take the H. A. of a star, planet, or the moon from the P.M. col. of Table 44. If the H. A. is east (which you can tell by the bearing of the star), subtract it from the star's R. A.; if H. A. is west, add it to star's R. A. The result is the R. A. of your meridian, or sidereal time at ship, and the long. is the difference between it and the G. Sid. T. The rule is the same for the moon and the planets.

Example: Dec. 1, 1917. Obs. alt. of Sirius, 20° 10′ 00″. Chronom. 11 hrs., 15 min., 00 sec. P.M. Chronom. slow of G. M. T. 1 min., 26 sec.; no I. E.; H. of E., 20 ft.; lat. 38° 58′ N. (See table on next page.)

It is good practice to make use of any hour-angle obtained from a chronometer sight for an azimuth. This is to be done by observing the compass bearing of the celestial body at the instant of taking the

G. M. T.	11 h. 16 m. 26 s. P.M.	Dec. Sirius..	16° 36′ 00″ S.
Sid. T. at G. noon	16 h. 39 m. 05 s.		90° 00′ 00″
Allowance	1 m. 51 s.	P. D.	106° 36′ 00″
	27 h. 57 m. 22 s.		
	24 h. 00 m. 00 s.		
Sid. T. at G.	3 h. 57 m. 22 s.		

Obs. alt.	20° 10′ 00″	Dip.	4′ 23″
Cor.	7′ 00″	Ref.	2′ 37″
T. C. A.	20° 3′ 00″		7′ 00″

P. D.	106° 36′ 00″	cosec.	.01804
Lat.	38° 58′ 00″	sec.	.10929
T. C. A.	20° 03′ 00″		
	2)165° 37′ 00″		
½-sum	82° 48′ 30″	cos.	9.09807
Diff.	62° 45′ 30″	sin.	9.94891
			2)19.17431
			9.58715

9.58715 =	3 h. 01 m. 54 s.	H. A. East.
	6 h. 41 m. 34 s.	R. A. of Sirius.
	3 h. 39 m. 40 s.	Sid. T. at ship.
	3 h. 57 m. 22 s.	Sid. T. at G.
Long. 4° 25′ 30″ W. =	17 m. 42 s.	

altitude, and then getting the true bearing from the tables. In case of working with a star whose declination exceeds the 23° given in the table, the true bearing may be computed by the altitude-azimuth problem, in conjunction with a chronometer sight. The rule for this is as follows:

Add together the P. D., lat., and the T. C. A. Divide the sum by 2 and call the answer half-sum; take the difference between the half-sum and the P. D., and call the answer diff.

Add together the secant of the lat., the secant of the alt., the cosine of the half-sum, and the cosine of the diff. Half their sum is the cosine of half the angle of the true bearing, which must be doubled and reckoned from north in north lat., and from south in south lat.

Example: Take the time sight of Sirius, just used, and work it for the azimuth.

P. D. . . .	106° 36′ 00″		
Lat.	38° 58′ 00″	sec.	10929
Alt.	20° 03′ 00″	sec.	02715
	2)165° 37′ 00″		
½-sum. . .	82° 48′ 30″	cos. . .	9.09807
Diff.	23° 47′ 30″	cos. . .	9.96146
			2)19.19597
		cos. . .	9.59798 = 66° 39′
			2
			N. 133° 18′ E. { truebear'g of Sirius

The beauty of the process is that the additional amount of work is so small. You already have the secant of the lat. and the cosine of the half-sum, and it takes only a few extra seconds to get the other two logarithms. When the time is accurately (not approximately) known, you can use this formula: sine of H. A. (expressed in degrees and minutes) + cos. dec. + cos. T. C. A. = sin. true bearing. The sine gives you the degrees and minutes, and you mark the bearing E. or W., as you see the body.

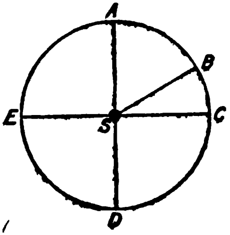
SUMNER'S METHOD

We now come to the most valuable of all known methods of finding a ship's position at sea. Two or three makeshift methods of finding the longitude might have been explained; but this is a purely elementary and practical work, and it is deemed useless to introduce infrequent workings when by Sumner's method we can find, at almost any hour of the day or night, the latitude, longitude, and error of the compass by simply working two chronometer sights. Furthermore, we can

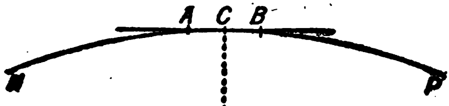
get a great deal of information from one sight.

Sumner's method is based on certain fundamental truths of navigation, which I shall now endeavor to explain, following pretty closely the admirable explanation of Captain Lecky.

Wherever the sun is, it must be perpendicularly above some spot on the surface of the earth. Suppose the sun to be immediately above the centre of the circle, S. Then if a man at A takes an altitude, he will get precisely the same one as men at B, C, D, and E, because they are all at equal distances from the sun, and hence on the circumference of a circle whose centre is S. Conversely, if several observers situated at different parts of the earth's surface take simultaneous altitudes, and these altitudes are all the same, then these observers must all be on the circumference of a circle, and *only one* circle. If



you moved one observer to the circumference of a larger circle, for instance, he

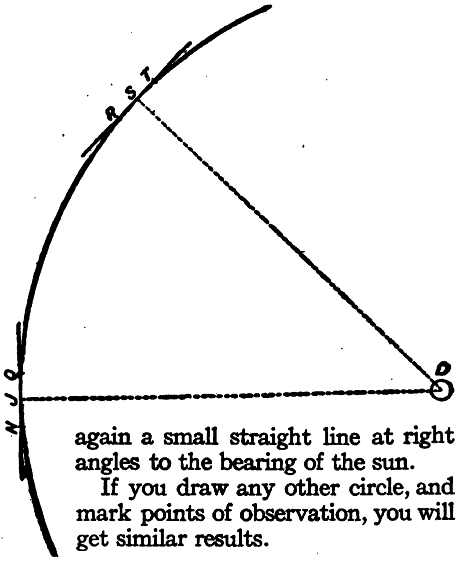


would be farther away from the sun and would get a smaller altitude.

Now such a circle on the surface of the earth would be very large—so large that a small arc of its circumference, say 20 or 30 miles, would be practically a straight line. Suppose D to be the point over which the sun is vertical, and HP to be part of the circumference of a circle drawn around this point. Suppose you were at C, and from an altitude of the sun you worked out your position. You would find yourself on the little arc AB, which to all intents and purposes is a straight line at *right angles to the true bearing of the sun from the point* C, as you may discern by simply looking at it.

Suppose now we continue the circle around D. Place an observer at J, and

let him take an altitude of the sun. He will be on the circumference of the same circle, but on the small arc QN, which is again practically a straight line and at right angles to the true bearing of the sun. At S he would find himself on the arc RT—



again a small straight line at right angles to the bearing of the sun.

If you draw any other circle, and mark points of observation, you will get similar results.

Hence: Any person taking an altitude of a celestial body must be, for all practical purposes, on a straight line which is at right angles to the true bearing of the body observed.

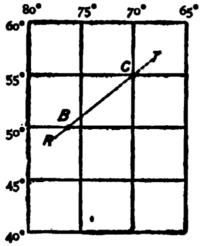
Such a line is called a Sumner line, or a line of position.

It must now be perfectly clear to the student that if the sun bears due north or south of the observer, the resulting line of position *must* run east and west; or, in other words, it is a parallel of lat. And that explains why a meridian observation gives the most accurate lat.

Again, if the sun bears due east or west the resulting line of position *must* run north and south; or, in other words, it is a meridian of longitude. And that explains why a prime vertical observation gives the most accurate longitude. The observer at J might be well over towards Q or N—in other words, mistaken considerably as to his latitude—but he would get his longitude all right.

But in the case of the man at S, the longitude cannot be known exactly unless the lat. is. Transfer the line to a chart. We know that we are somewhere on that

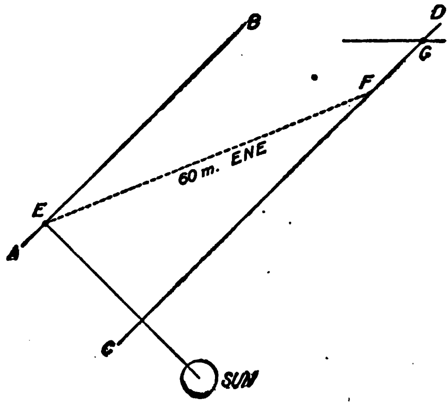
line RT. If the latitude is 50° N., we must be at the point where the line crosses the 50th parallel, which is at B. If the lat. is 55°, we must be at C. This shows how necessary the lat. is in cases where the observed body does not bear east or west. On the other hand, if you wished to get your lat. from the line RT, you would have to know your long. accurately. If the long. was 70° W., you would know you were at C.



Hence we get this operation from a single Sumner line: Whenever you take a chronometer sight of the sun, or any other heavenly body, from the H. A. obtained in the computation get the true bearing of the body from the azimuth tables, or by the alt.-azimuth problem. Then, through the position obtained, draw a Sumner line running at right angles to the true bearing.

You are absolutely sure to be somewhere on that line at the instant of observation; you cannot possibly be on any other.

Now suppose that you took the observation at 8 A.M., and that you were not quite sure of your lat. by D. R. From 8 A.M. till noon the ship sails 60 miles E.N.E., and then you get a meridian alt. and are sure of your lat. Through the point E, the 8



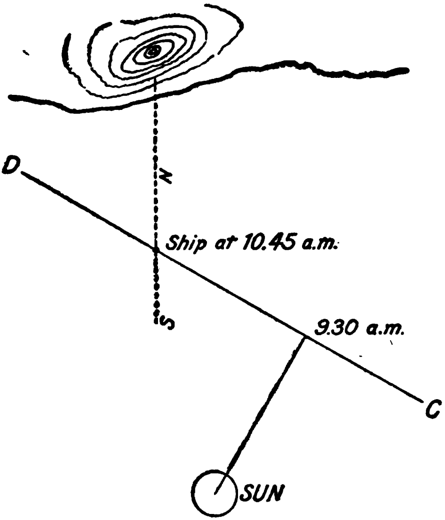
A.M. position, draw the Sumner line AB, at right angles to the sun's true bearing at 8 o'clock. From the point E lay off on the chart 60 miles E.N.E. on the line EF. At F, the extremity of EF, rule a new

Sumner line, exactly parallel to the old one. At the point G, where the parallel of your noon lat. cuts the Sumner line, is the position of the ship at noon.

The old established way of making a noon position is this: Take your morning sight for long., but do not work it out. Take your noon sight for lat., and then by D. R. compute backward to the correct lat. at the time of the morning sight, and with this lat. work out the longitude. Then carry the longitude up to noon by D. R., and thus establish the lat. and long. at noon.

The method by a Sumner line and a parallel is far shorter and quite as accurate. By it you have found that you are on small arcs of two different circles at the same time. You can be *only* at their point of intersection. And that is the whole theory of the Sumner method.

The old-fashioned way of working a Sumner line is to assume two latitudes, say 25′ or 30′ apart, and about equally distant from the lat. by D. R., work out the chronometer sight with each, lay down the two different positions on the chart, and rule a line joining them. This will be your Sumner line. But why do all that when



one working-out is sufficient? Any position at all must be on a line at right angles to the sun's true bearing, and that's your Sumner line.

Suppose you are approaching a coast on which there is a high mountain visible 60 miles at sea. There are reefs off the coast. You are uncertain of your lat. within 6 or

8 miles, but you fear you will reach the neighborhood of the reefs before noon.

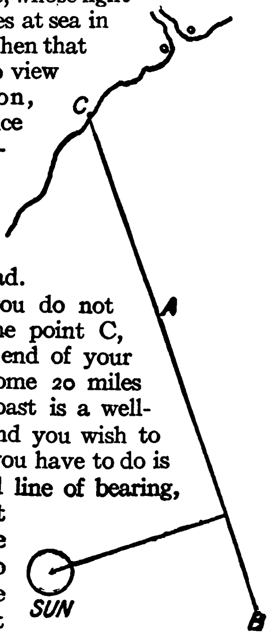
At 9.30 you get a chronom. sight and draw the Sumner line CD. Put the ship on that line and sail on it. At 10.45 you sight the mountain bearing N. true. Draw a line running N. and S. true till it cuts your line of bearing. That is your position. The only thing in the world that could put you wrong in this instance would be a current, and you must guard against that by using the lead according to the method of sailing along a chain of soundings already explained.

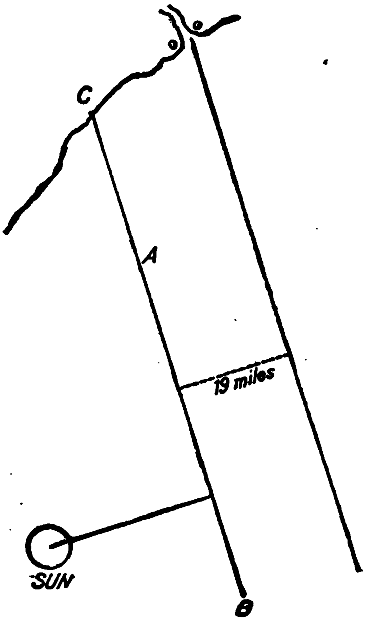
This introduces us to the excellent use of a single Sumner line when running in with the land. The simplest form of the operation is to take a chronometer sight and get a line of bearing. Suppose you are standing in towards a coast which you know to be northwest of you. Your position is not quite certain. You take a chronometer sight and get a position from which the sun bears W.S.W.¾W. You rule the Sumner line AB at right angles to it, running N.-by-W.¼W. Continue the line till it meets the land at the point C. Obviously if you sail on the Sumner

line heading N.-by-W.¼W. true, you will make the point C.

Suppose that at C there stood a well-known light-house, whose light was visible 18 miles at sea in clear weather. When that light popped into view over the horizon, you could at once verify your position by taking its bearing, and then sail in with boldness—not forgetting to use the lead.

But suppose you do not wish to make the point C, which is at the end of your Sumner line. Some 20 miles farther up the coast is a well-lighted harbor, and you wish to make that. All you have to do is to draw a second line of bearing, parallel to the first and ending at the point you wish to make. Measure the distance at





right angles between your two lines of bearing. Sail over that course and distance. You will then be on the second line of bearing, when you at once take the course N.-by-W.¼W. true, of the first line, and you are bound to make your harbor.

Let us see how this will work in practice. Suppose it to be late in the afternoon of a cloudy day in winter, and you are a little anxious because you have had no sights for longitude since 3 o'clock in the morning. Just before sundown the sun appears and you get a sunset sight.

Feb. 25, 1895. Lat. 30° 15′ N. The lower limb of the sun touched the horizon at 9 hrs., 32 min., 15 sec. by chronom. Chronom. fast of G. M. T. 3 min., 15 sec. Required a line of bearing.

```
G. M. T..9 h. 29 m. 00 s. P.M.
Cor. equ..   13 m. 10.8 s.
          ----------------
G. A. T...9 h. 15 m. 49.2 s.
          Dec.......9° 04′ 19″ S.
          Cor.......   08′ 50″
                    -------------
          Cor. dec...8° 55′ 29″ S.
Cor. dec... 8° 55′ 29″ S.
           90° 00′ 00″
          ------------
P. D......98° 55′ 29″ cosec..  .00434
Lat.......30° 15′ 00″ sec....  .06357
Const.....    21′
         -------------
        2)128° 49′ 29″
        --------------
½-sum....64° 24′ 44″ cos.... 9.63531
             21′
        --------------
Diff.......64° 45′ 44″ sin.... 9.95645
                             ---------
                            2)19.65967
                            ---------- h.  m.  s.
                             9.82983 = 5  40  08 A. T. S.
                                       9  15  49 A. T. G.
                                      ----------
          Long......53° 55′ 15″ W = 3  35  41
```

By Az. tables true bearing of sun = N. 108° W. Sumner line will run N. 18° W.

If, now, you had land to the northward your Sumner line would enable you to set a correct course to make it the proper place. As a matter of fact lat. 30° 15′ N. and long. 41° 21′ W. are well to the southward and westward of the Azores; but the principle remains the same.

If so much can be done with a single Sumner line, how much more can be done with two. If you can locate your ship on two Sumner lines at once, you know that she can be on but one place on either, and that is the point of intersection of both.

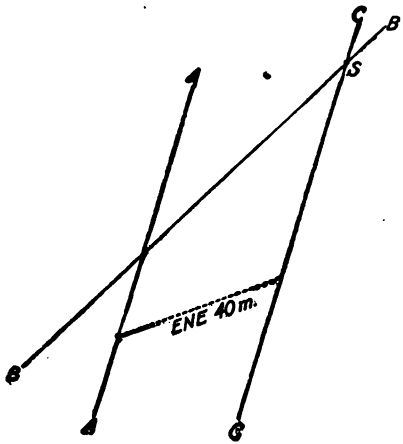
There are two ways of getting two Sumner lines, one by two successive observations of the same body, and the other by simultaneous observations of two bodies.

As applied to the sun the method is as follows: Take an observation, work it out with your lat. by D. R., and draw a Sumner line as already explained. Now wait till the sun's bearing alters at least 2 points. Take another observation and draw another Sumner line. It is obvious that it will make an angle of at least 2 points with the first one. The point of intersection of the two lines is the position of the ship.

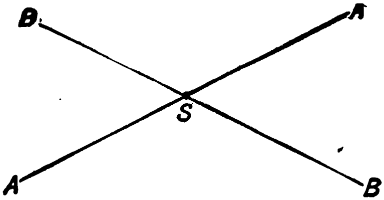
This, however, supposes the ship to be standing still. In practice she is making progress, and it becomes necessary to carry forward the first Sumner line to the place of the second observation. This is done by a process similar to that given for plotting a noon position.

Having taken your first sight and drawn your Sumner line, from *any* point on this line, lay off the course and distance made up to the time of taking the second sight and drawing the second Sumner line. At the extremity of the course-line draw a third line parallel to the first Sumner line, and prolong it till it cuts the second Sumner line. The intersection of this parallel with the second Sumner line will be the position of the ship at the time of the second observation. For instance, suppose that in the diagram your first observation gave you the line of position AA, and your second the line BB. Between the two sights the ship sailed E.N.E. 40 miles. You lay off E.N.E. 40 miles from any point on AA, and draw CC parallel to AA. The intersection of CC and BB at S is the position of the ship at the time of the second observation.

At night, however, you might get two stars, one east and the other west of you,



and take observations of both so closely together as to be practically simultaneous. Then your easterly star would give the line AA and the westerly star the line BB, and you would be at S (as on page 170).



EXAMPLE OF SUMNER'S METHOD WITH THE SUN

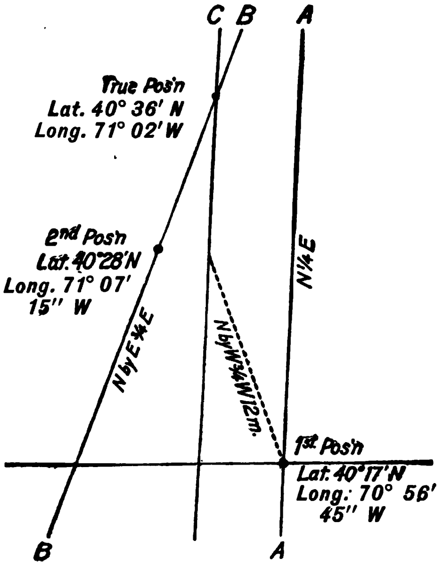
At sea, June 1, 1917. Obs. alt. ⊙ 33° 50′ 00″; G. M. T., 8 hrs., 55 min., 00 sec. P.M.; H. of E., 20 ft.; no I. E.; lat. 40° 17′ N. (See table on page 172.)

Two hours later took another sight, which gave a corrected alt. of 11° 15′. G. M. T., 10 hrs., 58 min. Ship in the meantime made 12 miles, N. 20° W. (See table on page 173.)

In practice the first sight would give the correct long., even were the lat. error much more than 8′, because the sun is only 1° off the prime vertical. Hence the navigator in a slow-sailing ship, doing 6 knots, could wait for a star or the moon to get his correct. lat.

But in a fast steamer—say a scout cruiser—this would not do. Nantucket

Shoals Lightship is in lat. 40° 37′ N., long. 69° 37′ W., and Block Island light in 41° 09′ N., 71° 33′ W. Evening is at hand, and you need to know your lat. as soon as possible. You cannot wait for moon or stars. But the Sumner method does your



G. M. T...... 8 h. 55 m. 00 s. P.M.
Equation.... + 2 m. 24 s.

G. A. T...... 8 h. 57 m. 24 s. P.M.

Dec.........22° 03′ 48″ N.
Cor......... 18″

Dec.........22° 04′ 06″ N.

Obs. alt......33° 50′ 00″
Cor......... + 10′ 19″

T. C. A......34° 00′ 19″

P. D..............67° 55′ 54″
Lat...............40° 17′ 00″
T. C. A..........34° 00′ 19″

2)142° 13′ 13″

½-sum.......... 71° 06′ 36″
Diff............ 37° 06′ 17″

cosec........... .03304
sec.............. .11756

cos.............. 9.51007
sin.............. 9.78047

2)19.44114

9.72057 = 4 h. 13 m. 37 s. A. T. S.
8 h. 57 m. 24 s. G. A. T.

Long., 70° 56′ 45″ = 4 h. 43 m. 47 s.

True bearing, N. 91° W.
Sumner line, N. 1° W.
(Sun practically in the prime vertical.)

G. M. T........	10 h. 58 m. 00 s.	Dec. 10 P.M. .22° 04′ 30″ N.	
Equation......	2 m. 23 s.	Cor. negligible.	
G. A. T........	11 h. 00 m. 23 s.		

P. D...........	67° 55′ 30″	cosec...........	.03309
Lat............	40° 28′ 00″	sec.............	.11874
Alt............	11° 15′ 00″		
	2)119° 38′ 30″		
½-sum.........	59° 49′ 15″	cos.............	9.70137
Diff...........	48° 34′ 15″	sin.............	9.87490
			2)19.72810
			9.86405

9.86405 = 6 h. 15 m .54 s. A. T. S.
11 h. 00 m. 23 s. G. A.T.

Long. 71° 07′ 15″ W. = 4 h. 44 m. 29 s.

True bearing, N. 71° W.
Sumner line, S. 19° W. (or N. 19° E.)

work. You find that you are 8 miles further north than your D. R. showed, and it is highly important information at this time.

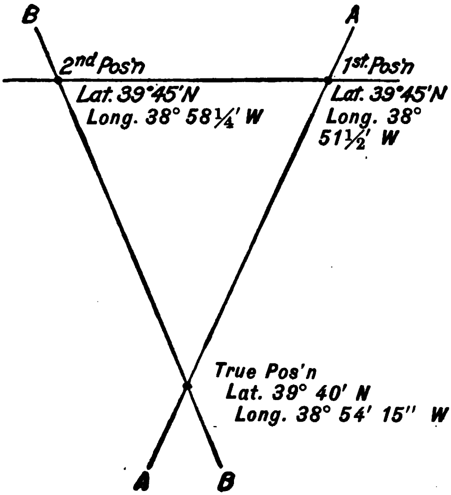
Now let us see what can be done with two well-chosen stars. To make a good choice, get two stars whose bearings from the ship are as nearly at right angles as possible. This will bring the intersecting Sumner lines nearly at right angles and make the position clearer. This computation, you see, is nothing more or less than astronomical cross-bearings.

EXAMPLE OF SUMNER LINES WITH TWO STARS

At sea, Jan. 1, 1917. Obs. alt. Procyon 32° 44′ 00″ E., and α Arietis 58° 21′ 00″ W.; lat. by D. R. 39° 45′ N.; H. of E., 20 ft.; no I. E.; G. M. T., first observation, 12 hrs., 01 min. P.M.; second obs., 12 hrs., 02 min., 10 sec. P.M. Required position of ship by Sumner's method. (See pp. 176–7.)

Plotted according to a scale of miles and with a protractor, the Sumner lines cut as below, making the true position lat.

39° 40′ N., long. 38° 54′ 15″ W. The lat by D. R. was 5¼′ in error.



It should be obvious to the student who has mastered the subject up to this point that all observations of celestial bodies give Sumner lines of position.

For this reason the navigator should

G. M. T.	12 h. 01 m. 00 s.	Dec. Procyon	5° 26′ 18″ N.
Sid. T. at G. preced. noon.	18 h. 42 m. 15 s.		90° 00′ 00″
	1 m. 58 s.	P. D.	84° 33′ 42″
	30 h. 45 m. 13 s.	Obs. alt.	32° 44′ 00″
	24 h.	Cor.	—5′ 51″
G. Sid. T.	6 h. 45 m. 13 s.	T. C. A.	32° 38′ 09″

P. D.	84° 33′ 42″	cosec.	.00196
Lat.	39° 45′ 00″	sec.	.11416
T. C. A.	32° 38′ 09″		
	2)156° 56′ 51″		
½-sum	78° 28′ 25″	cos.	9.30090
Diff.	45° 50′ 16″	sin.	9.85571
			2)19.27273
			9.63636

9.63636 = 3 h. 25 m. 12 s. H. A. East.
7 h. 34 m. 59 s. R. A. Procyon.

4 h. 09 m. 47 s. Sid. T. at ship.
6 h. 45 m. 13 s. G. Sid. T.

Long. 38° 51′ 30″ W. = 2 h. 35 m. 26 s.

Time bearing of *, N. 113° E.
Sumner line, N. 23° E.

G. M. T.	12 h. 02 m. 10 s.
Sid. T. preceding noon	18 h. 42 m. 15 s.
Allowance	1 m. 58 s.
	30 h. 46 m. 23 s.
	24 h.
G. Sid. T.	6 h. 46 m. 23 s.

Dec. α Arietis	23° 04′ 30″ N.
	90° 00′ 00″
P. D.	66° 55′ 30″
Obs. alt.	58° 21′ 00″
Cor. (Tab. 46)	— 4′ 59″
T. C. A.	58° 16′ 01″

P. D.	66° 55′ 30″	cosec.	.03624
Lat.	39° 45′ 00″	sec.	.11416
T. C. A.	58° 16′ 00″		
	2)164° 56′ 30″		
½-sum	82° 28′ 15″	cos.	9.11761
Diff	24° 12′ 15″	sin.	9.61270
			2)18.88071
			9.44035

9.44035 = 2 h. 08 m. 00 s. H. A. West.
2 h. 02 m. 31 s. R. A. α Arietis.

4 h. 10 m. 31 s. Sid. T. at ship.
6 h. 46 m. 23 s. G. Sid. T.

Long. 38° 58′ 00″ W. = 2 h. 35 m. 52 s.

True bearing of *, N. 113° W.
Sumner line, N. 13° W.

accustom himself to view all his operations as being applications of the fundamental principles of the Sumner method, and accordingly draw a Sumner line at right angles to the true bearing, as obtained from the azimuth tables for the local time of the observation, the lat. of ship and dec. of observed body.

Comparison with the compass bearing shows the error of the compass at the time of the observation, and the deviation on the course is readily ascertained.

The patent log should be read at the time of observation, in order that the course and distance made good between that and the next observation may be computed. This is essential to the carrying forward of a line of position, as previously described.

The value of the "Phi Prime" sight lies in its giving good latitude lines at intervals considerably removed from noon. A parallel of lat. is, of course, a Sumner line, and may be crossed with a line obtained by a time sight. These two lines may often be found in fairly close succession and the position of the ship fixed with a valuable approach to exactness.

Simultaneous observations of two stars are not easy to get, unless the horizon line is exceptionally clear. The navigator will oftener be able to get a star or a planet, and the moon on good moonlight nights, or still more frequently at evening or morning twilight.

ST. HILAIRE METHOD

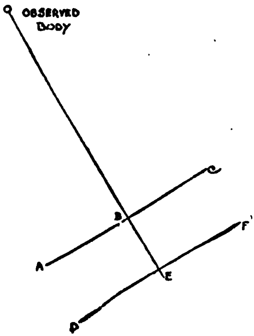
This method is rapidly gaining favor among navigators because of the celerity and certainty with which it arrives at results. Its fundamental principle is that when a Sumner line is laid down from an assumed position, the correct place of the line and the ship is determined by the difference between the calculated attitude of the celestial body at the assumed position and its correct altitude as shown by observation.

The observed alt. will prove to be higher or lower than the one computed for the assumed position. If higher, you are nearer to the body observed than you supposed; if lower, you are further from it.

The difference will be measured along

the line of the object's true bearing at the time of observation.

If AC is the assumed Sumner line, and the observed alt. is smaller than the calculated one, the true Sumner line will be represented by DF, and the difference will be the measurement of BE. Since this is an arc of a great circle, the distances on it are to be expressed in minutes (nautical miles).



There are tables obviating the necessity of computing the alt. of a celestial body as it would be at an assumed position. *Altitude, Azimuth, and Line of Position*, published by the Hydrographic Office, Bureau of Navigation, contains all the tables required in the whole operation.

The explanations of the uses of the tables will be found in the book. They are too long and elaborate for even an outline here.

Many navigators prefer to calculate the alt. at the assumed position instead of using the tables. There are three formulæ, of which the one apparently favored is that called the cosine-haversine formula. From this is obtained the calculated zenith distance of the celestial body at the assumed position, and hence the alt.

The necessary data are the H. A., lat. and dec. The H. A. is computed from the L. A. T. at the assumed place.

Table 45 (Bowditch) gives the log. haversines, and natural haversines in parallel columns.

Add the log. haversine of H. A., log. cosine lat. and log. cosine dec. Sum is log. haversine of arc called θ (theta).

Opposite log. hav. θ in Table 45 find nat. hav. of same arc. Take out this nat. hav.

If lat. and dec. are of same name, find diff. and take out its nat. haversine. If they are of different names, add, and take nat. haversine of sum.

Nat. haversine of θ + nat. haversine of sum or diff. of lat. and dec. gives natural haversine of calculated zenith dist. $90^\circ - $Z. D. = calculated altitude.

Diff. between this and observed alt. is the altitude difference.

When an assumed position is determined, get the true bearing of the object from the azimuth tables, using assumed lat., dec., and H. A.

When alt. difference has been found, you may lay it off by the scale of your chart on the line of the azimuth, as already described, or you may compute the position by treating the alt. diff. as a distance and the bearing as a course.

The following example is taken from Bowditch. May 18, 1916, A.M. Lat., 41° 33′ N. Long., 33° 37′ W. by D. R. T. C. A., 29° 50′ 04″. G. A. T., 21 hrs., 46 min., 35 sec. Dec., 19° 31′ 18″ N.

Assumed position, lat. 41° 30′ N., long., 33° 38′ 45″, or 2 hrs., 14 min., 35 sec. W. Azimuth, N. 89° 45′ E.

G. A. T.	21 h. 46 m. 35 s.
Long.	2 h. 14 m. 35 s.
L. A. T.	19 h. 32 m. 00 s.

[You may take out the log. haversine for this L. A. T., or for the sun's easterly hour-angle, which is 24 hrs. – 19 hrs., 32 min., 00 sec. = 4 hrs., 28 min. This

gives the same log. haversine as 19 hrs., 32 min.]

H. A.	4 h. 28 m.	log. hav.	9.48378
Lat.	41° 30′ N.	......log. cos.	9.87446
Dec.	19° 31′ 18″ N.	..log. cos.	9.97429
		log hav.	9.33253
		nat. hav.	0.21505
Lat.−Dec.	21° 58′ 42″	nat. hav.	0.03634
Calculated Z. D.	60° 11′ 00″	nat. hav.	0.25139
	90° 00′ 00″		
Calculated alt.	29° 49′ 00″		
Observed alt.	29° 50′ 04″		
Alt. diff.	1′ 04″		

Observed alt. being the higher, you are nearer the sun than the assumed position. Lay off alt. diff. N. 89° 45′ E. one mile, or by table:

Course	Dist.	Diff. Lat.	Dep.	Diff. Long.
89° 45′	1.0	0′ N.	1′ E.	1.3 E.

Lat. 41° 30′ N.	Assumed long.	33° 38′ 45″ W.
	Diff. long.	1′ 18″ E.
	Correct long.	33° 37′ 27″ W.

Sumner line, N. 0° 15′, and S. 0° 15′ E. at right angles to azimuth.

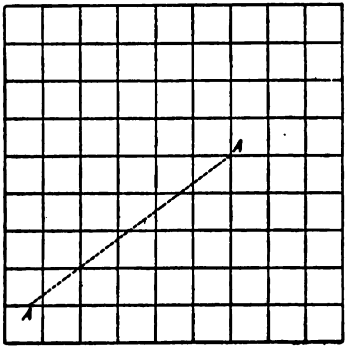
The student who has advanced this rar should have no difficulty in learning the other formulæ from Bowditch.

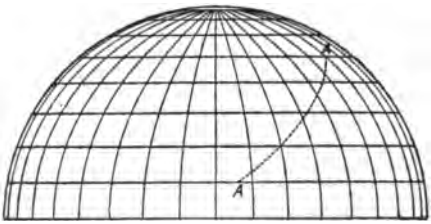
This method can be used with celestial bodies anywhere from the meridian to the P. V. Bowditch gives an example of its use with an H. A. of 7 min., and explains how it can be used practically to the exclusion of other workings. It is favored by Navy navigators and should be learned by all students intending to seek commissions.

GREAT-CIRCLE SAILING

It is a peculiar fact that on a Mercator's chart a straight course between two places appears as a curve. This is owing to the expansion of the degrees of lat. and long. towards the poles, in order to construct the chart on the theory that the earth is a cylinder, as already explained. The converse is equally true: that a straight line ruled on a Mercator's chart is really a curve when you come to sail on it.

This is easily seen when you draw the two lines on flat or spherical surfaces. As the meridians of longitude constantly converge towards the poles, and as courses are all measured by the *angles they make with the meridians*, it naturally follows that





when you draw the meridians all parallel to one another, you must be distorting an actual course when you make it cut all these meridians at the same angle. Drawn on a sphere, your straight course would become a curve, known as a rhumb line. (See diagram.)

Great-circle charts can be obtained, and on them all great-circle tracks appear as straight lines. But Sir George Airy, Astronomer Royal of Great Britain, designed a method of drawing a correct great-circle track on a Mercator's chart. His method is as follows:

Connect the point of departure and that of destination by a straight line, and find by measurement the centre of the line.

Draw from this central point, at right angles to the line first drawn, a second line, and continue it beyond the equator if necessary.

With the middle lat. between the two places enter the appended table, and take out the lat. under "corresponding parallel." The perpendicular line must reach and intersect this parallel.

Now put one point of the dividers in this intersection, and with the other point describe a curve which will pass through the point of departure and that of destination. This curve will be the great-circle track.

The blank spaces arise from the fact that in such relations great-circle sailing is of no advantage. Within the tropics, for instance, it is of little use, because the dis-

tortion of the degrees on a Mercator's chart is so small.

A ship on a great-circle track, except when on the equator or sailing N. or S. true, must change her course often in order to keep on the track. Here the principle that a small arc of a large circle on the earth's surface is practically a straight line may be employed, and the successive courses laid off as usual with parallel rules and dividers. You may find the distance on a great-circle course with close approx-

Middle Lat.	Corresponding Parallel opposite Name to Lat. of Places	Middle Lat.	Corresponding Parallel same Name as Lat. of Places
20°	81° 13′	*	*
22°	78° 16′	*	*
24°	74° 59′	*	*
26°	71° 26′	*	*
28°	67° 38′	50°	4° 00′
30°	63° 37′	60°	9° 15′
32°	59° 25′	62°	14° 32′
34°	55° 05′	64°	19° 50′
36°	50° 36′	66°	25° 09′
38°	46° 00′	68°	30° 30′
40°	41° 18′	70°	35° 52′
42°	36° 31′	72°	41° 14′
44°	31° 38′	74°	46° 37′
46°	26° 42′	76°	52° 01′
48°	21° 42′	78°	57° 25′
50°	16° 39′	80°	62° 51′
52°	11° 33′	*	*
54°	6° 24′	*	*
56°	1° 13′	*	*

imation by computing the lengths of these short courses and adding them.

To find the courses to be sailed, get the difference between the course at starting and that at the middle of the circle, and find how many quarter-points are contained in it. Divide the distance of half the great circle by this number of quarter-points, and that will give the number of miles to sail on each quarter-point course.

Suppose the course at starting to be N.E., and at the centre E.N.E., and the distance from start to centre 800 miles. The difference between N.E. and E.N.E. is 2 points, which = 8 quarter-points. Divide 800 by 8, and you get 100 miles for each quarter-point course. In other words, every 100 miles you change the true course a quarter of a point easterly.

Bear in mind that this means *true course*. Compass course must allow for variation and deviation.

Accurate method of measuring the distance on a G.-C. track.—Turn the largest course (always one of the end courses) into degrees. Then add the cosec. of the largest course, cosine of the smallest lat., and sine of the diff. of long. between the

two places. Answer will be sine of the distance in degrees and minutes. As these are degrees and minutes of a great circle, which, like the equator, extends around the full circumference of the earth, multiply the degrees by 60 and add the minutes, and the result is the distance required.

If the sine of the distance gives more than 90°, subtract the angle from 180°, and use the sine of the remainder.

DISTANCE AND DANGER-ANGLES

If near a coast, it is imperatively necessary that the navigator should have quick and certain methods of ascertaining his distance from well-marked points, and of avoiding hidden dangers set down on the chart.

When a light or a mountain first appears above the horizon, its bearing should at once be taken by compass, and the navigator should consult Table 6, Bowditch, which gives the distance at which elevated objects can be seen at sea. The height of the object when first seen above the horizon and the height of the observer must both be taken into account. Thus:

At sea, running for Block Island Channel, Block Island Light, 204 ft. above the level of the sea, appeared above the horizon. Observer on bridge 25 ft. above sea. Required distance of light.

Table VI.. 200 ft. =	18.63	miles' range of visibility.
" " .. 25 ft. =	6.59	" " "
	25.22	miles, distance of light.

Uncommon refraction will sometimes make a light appear sooner than it ought to, and the navigator must be on the lookout for such phenomena. In fact, the whole operation is not to be accepted as infallible, for at the best it gives uncertain results.

The vertical angle of an object above the water-line, measured by the sextant, may also be used to give the distance. The navigator should possess Captain Lecky's *Danger Angle and Off-Shore Distance Tables*, in which are given the sextant angles for heights up to 1000 ft. The vertical angle can be used with these tables when the object is partly below the horizon, or when it is between the horizon and the observer. Tables 33 and 34, Bowditch, are used in the Navy. If the object is far away, and the angle consequently

very small, it should be measured both on and off the arc. For instance, with a light-house, first bring down the centre of the lantern (just as you would bring the sun) to the horizon, and read the angle. Then bring *up* the horizon line to the centre of the lantern by moving the index bar of the sextant towards you, and read that angle. Take the mean of the two, and enter the tables under the height of the light. Opposite the sextant angle (or the nearest one to it) take out the distance. With a mountain bring down the top to the horizon. If the object is between you and the horizon, use the object's water-line.

Example: Oct. 5, 1917, bound west, passing Shinnecock Light, bearing N.-by-W.-½W. by compass, desired to know distance of ship from it. Vertical sextant angle, from centre of light to water-line, measured on and off, 22′ 45″.

In table under 160 ft. and opposite 22′ 50″, distance given is 4 miles.

Aboard U. S. men-of-war the stadimeter or range-finder may be used to find the distance of any object on shore not beyond its limits.

For passing concealed dangers the ver-

tical sextant angle is used thus: Suppose that 300 yards to the eastward of a light 45 ft. high, which you must pass on the easterly side, lies a shoal spot or a reef dangerous to you. You therefore decide to pass 300 yards outside of it, or 600 yards from the light. Under 45 ft. and opposite 600 yards you find the angle 1° 26′. You set the sextant at that angle, and watch for the image of the light in the horizon-glass. As long as the angle between the light and the water-line is 1° 26′ or *less*, you are 600 yards or more from the light. If the angle becomes more, you are inside of 600 yards. You need not move the index bar at all, for if the light rises above the water-line as seen in the horizon-glass, the angle is larger than that set, and in this case that means danger; but if it drops below, the angle is smaller.

This same method of angling is used in keeping the distances between war-ships steaming in squadron. At night each ship carries a white light at her fore-truck, and the angular elevation of this light is watched. In daytime keep the truck itself at the water-line. The elevation of the mast is known. Ships in squadron

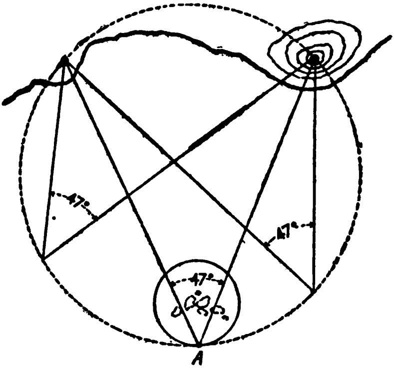
always keep memoranda of the angles of their consorts for distance, half-distance, and double-distance. The masthead angle can also be used to set a target at a given distance from the ship.

The horizontal danger angle is at times extremely valuable, and the navigator should master its use. It is first necessary to learn to take horizontal angles with the sextant. Hold the instrument face up. Look through the sight-vane and horizon-glass at the left-hand object, and push the index bar forward till the right-hand object makes contact with it. Then read the angle.

It is a good plan to take cross-bearings this way, noting the compass bearing of one of the objects. The bearing of the other is at once known by the angle between the two. If the ship's head should fall off between the bearings, and change the deviation, you would have only one deviation to apply.

The horizontal danger angle is used in passing hidden dangers. Suppose you wish to pass at a distance of a quarter of a mile outside of some hidden rocks, and on the shore are certain objects, say a light-house

and a mountain, marked on a chart. Draw a circle around the rocks with a radius of a quarter of a mile. Now describe another circle that will pass through the light-house, the church, and the most seaward part of your first circle. From this last



point, A, draw lines to the light-house and the church. Now measure with a protractor the angle at the juncture of these two lines. Set that angle (47° in the diagram) on the sextant, and watch the selected objects with instrument face up.

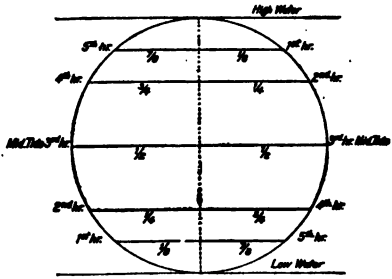
The moment your two objects appear in the horizon-glass you are close to your circle of safety, and when they make contact you are on it. All you have to do is to alter the course of the ship so as to keep the contact, and so sail around the outer part of your circle till you have rounded the rocks. If you watch the angle closely this cannot fail, and in narrow waters it is an invaluable method.

In measuring vertical danger angles get as close to the water as possible, so as to remove error caused by your height above the water. This error, however, will increase your angle and thus place you farther away from the danger; so that you will be all right unless you have a second danger close aboard on the other side.

ALLOWANCE FOR TIDES

In fixing positions by lights, mountains, etc., in passing over shoals, and in berthing ship at anchorage, bear in mind that *heights* are recorded on charts as measured from *high*-water, ordinary spring tides, while *soundings* are for *mean low*-water.

To find the rise of the tide or its fall.—Use the following diagram:



The right-hand side shows how the tide falls = 1/8 of its range for the first hour, 1/4 at the end of the second, 1/2 at the end of the third, and so on. The left-hand side shows how it rises.

Remember that the rise and fall do not coincide with the change of tidal current. You must ascertain the duration of the ebb and flow from the published sailing directions, such as the *Atlantic Coast Pilot.*

Where the range of the tide is great, you must allow for it in measuring angular altitudes of shore marks.

A log-book contains the record of the day's work of the ship. It may be made very simple or very elaborate. The ordinary merchant service log-book is quite simple. The data to be put in the book are noted on a log-slate by the watch officers and afterwards transferred to the log-book. A simple and satisfactory form of log is shown on page 198.

The hours, contained in the first column, are numbered from noon till noon. The second column contains the knots, and the third the fathoms, which are eighths of knots. The entries to be made in the remaining columns are perfectly apparent. Winds should never be entered in fractions, but in whole points.

The form of log used in the U. S. Navy is exhaustive. The log is kept by the watch officers in a "rough-log" book, and afterwards copied in the official book by the ship's writer. Each officer signs that part of the log for which he is responsible with his full name and rank. Junior watch officers record the readings of the barometer and thermometers, state of clear sky, and

H.	K.	F.	Courses	Winds	Lee-way	Remarks
1	6		S.S.E.½E.	E.-by-N.	¼	Wind increasing till dog-watches; moderate thereafter. Fair weather. Smooth sea.
2	6					
3	7	1				Stayed masts, set up rigging, and rattled down fore and aft.
4	7	2	....	....	....	
5	8					
6	8					
7	8					
8	7					
9	7		E.N.E.	S.E.-by-S.	½	Tacked ship.
10	6					
11	6					Alt. * Altair E. of merid., 15° 44′ 40″. Chro. 2 h. 24 m. 56 s. A.M. Long. 16° 03′ 00″ W.
12	6	....	....	....	....	
1	5					
2	5					
3	5					
4	5					
5	5	3	E.-by-N.	S.S.E.	¼	
6	5	6				Spoke bark *Pegasus*, Morton, master, bound west.
7	6	2	....	....	....	
8	6					
9	6	2				
10	7	4				
11	7					Merid. alt. ⊙ 73° 39′ 20″ S. = Lat. 39° 35′ 56″ N.
12	6	3	....	....	....	

Course made good	Dist.	Diff. lat.	Dep.	Latitude N.		Diff. long.	Longitude W.		Bearing and distance of port of destination at noon. Europa Point
				D. R.	Obs.		D. R.	Obs.	
E. 17° S.	153′	44.4′	146′	39° 37′	39° 36′	191′	14° 21′	14° 03′	S. 63° E. 592 miles.

condition of sea. (See table on pages 200–201.) Then follows the form for the remaining 12 hours, which is similar. These forms fill the left-hand page. The right-hand page is headed "Record of Miscellaneous Events of the Day," and contains the running record of the business and weather of each watch.

RATING A CHRONOMETER

It is sometimes necessary on a long voyage to ascertain the daily gain or loss of the chronometer, owing to the fact that the rate may be affected by extremes of temperature or other causes. The navigator may be far away from a maker, and hence must know how to ascertain the rate for himself. To perform the operation he will require an artificial horizon. This consists of a small trough, which is filled with absolutely clean mercury, and covered with a glass case which permits the observer to see the reflecting surface, and yet keeps wind and dust away from it.

The observer must now go with his sextant, chronometer, and artificial horizon to a spot where the longitude is accurately

Hour	Knots	Tenths	Reading of Patent Log	Average		Reading of Engine Counter	Courses Steered by Standard Compass	Wind	
				Steam	Revolutions			Direction by Standard Comp.	Force
8 A.M.									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
Noon									

A.M. { Lat. ....
A.M. { Long. ....

Noon:
- D. R. { Lat. .... / Long. ....
- Obs. { Lat. .... / Long. ....
- Current { Set .... / Drift......
- Made Good { Course. / Dist....

8 P.M. { Lat. ....
8 P.M. { Long. ....

Magazine Temperature......
Maximum.................
Minimum.................

Compass { Error on Course / Variation...... / Deviation.....

Coal { Received........ / Expended....... / On hand.......

Fuel Oil { Received......... / Expended........ / On hand.........

Water { Distilled......... / Received........ / Expended....... / On hand........

Barom.		Temperature			State of Weather by Symbols	Clouds			State of Sea
Height in Inches	Thermometer Attained	Air, Dry Bulb	Air, Wet Bulb	Water at Surface		Forms by Symbols	Moving From	Amount—Scale 0 to 10	

DRILLS AND EXERCISES

Morning	Afternoon
1st Division	1st Division ....
2d "	2d " ....
3d "	3d " ....
etc.	etc.

known to a fraction of a second. This will obviously be on shore, and that is why the artificial horizon must be used.

The observer should station himself, sitting, if possible, so that the artificial horizon will be in a direct line between himself and the body to be observed, and the image of the body will be shown in the mercury. Look through the sight-vane of the sextant, so as to see the image in the mercury through the horizon-glass. Bring down the image reflected by the sextant mirror till it makes contact with the image in the mercury. At that instant note the chronom. time.

The angle of altitude shown by the sextant will be double what it would be with a sea horizon, and must therefore be divided by 2. The altitude is corrected as usual, except for height of the eye, which does not exist in this operation.

The remainder of the operation consists of finding the local mean time, and, by applying the longitude, the correct G. M. T. at the instant of observation. Thus the error of the chronom. is found. The observer now waits not less than six days (ten days are better), and then repeats the

process at the same place. From the difference in the error on the two dates you get the daily rate.

For instance, suppose that on May 2, 1917, at Falmouth, Eng., you set out to rate your chronom. with artificial horizon and the sun. Your altitude, worked out according to the rule for a chronom. sight, gives you app. time at Falmouth 6 hrs., 53 min., 22 sec. A.M. Apply the corrected equation of time and get Falmouth M. T., 6 hrs., 50 min., 07.8 sec. The longitude of Falmouth is 5° 02′ W. = 20 min., 08 sec. Add this to Falmouth M. T. and you get 7 hrs., 10 min., 15.8 sec. G. M. T. At the instant of observation the chronom. showed 7 hrs., 18 min., 18 sec. A.M.; chronom. fast of G. M. T., 8 min., 02.2 sec.

On May 8 you repeat the process, and find that the chronom. is 8 min., 05.2 sec. fast of G. M. T.

May 2............	8 m.	02.2 s
May 8............	8	05.2
Gain in 6 days....		3 s. = Daily rate 0.5 s.

Of course you can use the stars or planets for this work just as well as the sun. Whatever you use, bear in mind these facts: If the celestial body is rising (east

of meridian), the two images seen through the horizon-glass will separate, provided you are using the lower limb. If the body is sinking (west of meridian), they will close.

Chronometers may be rated in many ports without observation by means of public time signals, such as time balls or guns, which mark a given hour either of local or G. M. T.

CARE OF A CHRONOMETER

(Condensed, by permission of T. S. and J. D. Negus, from their paper read before the Naval Institute)

Be careful in carrying a chronometer never to give it a horizontal twist. This motion will affect the balance to such an extent as to throw the chronometer a second or a second and a half out of time.

The gimbals must be secured so as to prevent the chronometer from swinging while being carried. There is a stay for this purpose. Aboard ship the instrument should be allowed to swing.

Keep a chronometer aboard ship always in its outside case, in an apartment well ventilated, yet free from draughts. Never put a chronometer near wood which is in contact with salt-water.

Never open the outside case except when winding or taking time.

In damp countries wrap a blanket around the outside case.

You cannot do too much to protect a chronometer from rust. A small spot will change the rate of the instrument.

Wind the chronometer every day at the same hour, unless it is an eight-day chronometer; then wind it once every week at the same time.

In winding, turn the chronometer bowl over in the gimbal slowly with the left hand, slide the valve by pressing the forefingers of the left hand against the nail-piece on the valve until the key-hole is uncovered, insert the winding key with the right hand, and wind to the left till a decided stop is felt. After removing the key, do not let the chronometer of its own accord drop to its level, but let it down carefully until horizontal.

Never let a chronometer get within the magnetic influence of a compass or an electro-magnet.

If a chronometer has run down and needs to be started, wait till the hands indicate the proper time, and then start it by a slight horizontal twist.

All chronometers reach their highest gaining or losing rate at a certain temperature. Those used in the United States Navy, made by Negus, reach their fastest rate at 70° F. Any exposure of the instrument to other temperatures will change the rate. The average temperature correction, as given by the makers, is .0025 second, multiplied by the square of the difference in the number of degrees of temperature. Thus, to find the correction to be made to the rate of a chronometer in a temperature of 80°, multiply .0025 by the square of the difference between 70° and 80°. A chronometer with a rate of +1 sec. at 70° would show the following variations:

55°	60°	65°	70°	75°	80°	85°
+ .4375 s.	+ .75 s.	+ .9375 s.	+ 1 s.	+ .9375 s.	+ .75 s.	+ .4375 s.

Chronometers should be cleaned and oiled at least once every three years and a half.

Vessels destined for long voyages should carry three chronometers. If you have two and one goes wrong, you cannot tell which is in error. With three you can

make daily comparisons and know pretty well what they are doing.

Keep your chronometers away from iron. It affects the going of the instruments.

If you have to carry a chronometer, use the leather strap attached to the case, and be careful not to swing the instrument or let it knock against anything.

In transporting a chronometer overland (by rail, for instance), put it in a basket resting on plenty of cotton or some other substance that will keep it from jarring.

THE NAVIGATOR'S ROUTINE

Before leaving port ascertain the exact draught of your vessel. Also ascertain the height of your eye above the water-line at all points available for taking observations.

As soon as you are on open water fix the position of the ship by cross-bearings, by vertical or horizontal angle and compass bearing, or by compass and range-finder.

This is called taking departure, and is entered in the log opposite the hour thus: "Sandy Hook Lightship bearing S. 15° W.,

distant 2 miles, from which I take departure."

From the moment of taking departure begin the record of the course and distance for each hour in the log-book.

In all your work make it an invariable practice to write the name or initials of each item in a formula, as T. C. A. (or h, the symbol), secant, cos., etc. This will save you frequent confusion and often error.

Ascertain at night from azimuth tables the hour when the sun will bear most nearly east next morning.

For this purpose local app. time need be known only approximately

Hack watch can be set accordingly.

To ascertain the watch time to take the morning obs., compare watch with chronom. the night before. Get from N. A. the dec. of sun for next A.M. and work up lat. by D. R. With these enter azimuth tables and find right time to take A.M. sight. An example will best show the rest of the work.

July 18, 1917, you find that next morning, about 8 A.M., your lat. will be 35° 10′ N., long., 60° 12′ W.

Azimuth of 89° 34′ is given for lat. 35°, dec., 21°, same name, at 8 hrs., 10 min., A.M.

Cor. chronom. reading at time of watch comparison	12 h. 00 m. 20 s.
Equation of time	—6 m. 01 s.
G. A. T. at comparison	11 h. 54 m. 19 s.
Long. 60° 12′ W. = 4 h. 00 m. 48 s.	4 h. 00 m. 48 s.
L. A. T. at time of comparison	7 h. 53 m. 31 s.
Watch T. at time of comparison	7 h. 34 m. 22 s.
Watch wrong on L. A. T. for 8 A.M. sight	19 m. 09 s. slow
Time of 89° 34′ azimuth	8 h. 10 m. 00 s.
Watch-time to take A.M. sight	7 h. 50 m. 51 s.

Hence take the sight when the watch shows 7 hrs., 51 min., and the sun will be on the P. V. When the watch shows 7 hrs., 51 min., the correct L. A. T. will be 8 hrs., 10 min., 08 sec.

In morning note comparison of hack watch or hack chronom. with standard chronometers.

Ascertain index error of sextant.

Take A.M. long. sights at time determined as above. Always take at least three sights at equal intervals of time. Use mean of altitudes and times in working out. This reduces possible errors.

At time of sight take bearing of sun by

standard compass for determination of deviation.

Work up lat. (by D. R.) from last previous fix.

Compute long. with this lat.

Ship's clocks may now be set by L. M. T. ascertained in working long.

With this long. and sun's bearing, taken as above directed, lay down Sumner line of position.

If any Sumner lines have been taken in the early morning hours, run them up to the new line and get ship's position as directed on page 168.

Ascertain compass error from azimuth taken at time of long. sight.

If ship is running at high speed, or approaching land, or on scouting duty, work out other lines of position between morning and noon sights.

When the sun is not too near the meridian, and conditions are as noted on page 122, get a ϕ' observation.

Between A.M. sight and noon determine exact run of ship.

To determine the exact run from time of A.M. sight to noon and to set watch to L. A. T. of position to be reached by ship at

local app. noon, remember that watch must be set back for westerly change of long. and forward for easterly.

Enter Table 2 with the course and the hourly speed of ship as dist. Find the diff. long. made from 8 A.M. sight to 11 A.M. Apply this to watch-time to ascertain error of watch (W.) at 11 A.M.

For example, at A.M. sight W. was 19 min., 08 sec. slow. Suppose your change of long. to 11 A.M. is 2 min., 45 sec. east, then at 11 W. is 21 min., 53 sec. slow, and the time to noon will be 1 hr., − 21 min., 53 sec. = 38 min., 07 sec. Now get the diff. long. for the ship's run in 38 min., 07 sec., which is the change between 11 A.M. and noon. Let us suppose it amounts to 30 sec. You will have this result:

Watch slow at 8 A.M. sight..............	19 m. 08 s.
Change to 11 A.M......................	2 m. 45 s.
Change from 11 to L. A. noon...........	30 s.
Total change......................	22 m. 23 s.
Run to noon, 4 hrs. — 22 m. 23 s. = ...	3 h. 37 m. 37 s.
Run from A.M. sight to noon = knots per hr. multiplied by......................	3 h. 37 m. 37 s.

Before, or about 11.30, set ship's clock to local time of coming noon position according to long.

If ex-meridian altitudes are taken before

or after noon, remember that, if the ship is on any course appreciably away from true N. or S. she will change her long. and hence her L. A. T. Therefore, compute by D. R. diff. long. on course and dist. run between setting of clock and taking ex-merid. Turn diff. long. into time and apply to clock time in order to find correct interval from noon, or local H. A. of sun.

Work up constant for noon observation, page 116.

12 M. (App. T.) noon sight for lat.

Work lat. back by D. R. to time of A.M. sight for long. to ascertain how much in error assumed lat. at that sight was.

Enter Table 47 with the lat. used in A.M. sight applied at top, and the true bearing of observed body at side. Take out what is called the long. factor (symbol F) or error of long. for each minute of error in lat. Multiply the factor by the number of minutes of difference between assumed and true lat. to get correction to be applied to long. If the diff. between the two latitudes is of the same name (N. or S.) as the first letter of the azimuth, the alteration of the long. must be made in the direction contrary to that indicated by

the second letter of the azimuth (E. or W.). It will be obvious to the student that azimuths in these workings must always be reckoned from the meridian of the compass.

Carry corrected long. to noon by D. R.

Plot ship's noon position. Can also be done by Sumner lines (page 160).

Owing to inevitable errors, a vessel's position is rarely determined within two miles. Therefore draw a circle with a radius of 2 miles, and regard the ship as possibly anywhere within it. Plot next course from circumference.

After obtaining correct noon position, compute course and distance made good in day's run.

Compute total course and dist. from port of departure; also from port of destination. Difference between position by D. R. and that by obs. is usually attributed to current; errors in steering, etc., however, are as much responsible.

In the afternoon work time sight when the sun bears most nearly west.

Establish lat. at favorable time after noon by "Phi Prime" sight.

Carry the P.M. lat. and long. up to 8 P.M., when minimum day's work ends.

Since, however, the most accurate "fixes" are obtained from observations of two bodies at the same time, the navigator should utilize evening and morning twilights when the best horizons, and hence the best results, are to be had.

Sunset or sunrise sight of the sun, simultaneous lat. and long. sights of two bodies (stars, or star and moon, for example), or simultaneous sights of opposite bodies giving intersecting Sumner lines (page 174), should be taken. Positions on single Sumner lines can be corrected by the St. Hilaire method (page 179).

Bear in mind always in selecting bodies for observation that when your lat. and the dec. of the body are nearly the same, you can get a good long., but not a good lat. As the body's dec. and your lat. separate, long. observations become less favorable, till, with a body approaching the meridian, the latitude, not long., must be found.

With a body near the prime vertical, or not near meridian, use your observation for long.

When near or within 45° of the merid. use your observation for a "Phi Prime" sight.

When body is close to merid. use ex-merid. method (page 120).

St. Hilaire method is available at *all* times.

Charts expressly made for plotting positions can be obtained. They save the sailing-chart from pencil-marks and rubber-smudges.

Before approaching land acquaint yourself with lights, fog signals, soundings, buoys, etc., as shown on chart.

Be ready to recognize any light as soon as seen. If flashing, time the length of flash and length of interval when light is still distant. This will aid in identification, and sometimes make it certain.

Before entering a harbor note ranges, length of courses to be steered between turning-points, etc. If danger-angles have to be used, plot them beforehand.

Change course at precise turning-point. Note time and read patent log.

If weather is thick, steer from buoy to buoy along channel, allowing for tidal current.

If you fail to make a buoy at computed time, anchor at once.

On reaching anchorage in harbor, plot your position on chart by three bearings of charted objects situated so as to make sharply intersecting lines.

EXAMPLES FOR PRACTICE

DEAD-RECKONING

Suppose a ship to sail upon the following courses and distances: S.E.-by-S., 29 miles; N.N.E., 10; E.S.E., 50; E.N.E., 50; S.S.E., 10; N.E.-by-N., 29; W., 25; S.S.E., 10; W.S.W.½W., 42; N., 110; E¾N., 62; N., 7; W., 62; N., 10; W., 8; S., 10; W., 62; S., 7; E.¾S., 62; S., 110; W.N.W.½W., 42; N.N.E., 10; and W., 25. Required the course and distance made good (Norie).

Ans. The ship has returned to the place she started from.

From lat. 40° 3′ N., long. 73° 28′ W., ship sails S.E.-by-S., 36 miles, variation ½ pt. west; S.E.-by-S., 8 miles, variation ¼ pt. west; S.E.½E., 28 miles, with half a point of leeway on the starboard tack and variation ¼ pt. west. Ship has been 8 hrs. in a current setting N. E. (variation ¼ pt. W.) at the rate of 2 knots per hr. Required lat. and long. in and course and distance made good (Patterson).

Ans. Lat. 39° 26′ N., long. 72° 07′ W., course S. 60° E., dist. 72 miles.

SHAPING COURSE BY MERCATOR'S SAILING

Required the bearing and distance of Pernambuco, lat. 8° 4′ S., long. 34° 53′ W., from Cape Verde, lat. 14° 45′ N., long. 17° 32′ W. (Norie).

Ans. S. 37° W. (217°), dist. 1715 miles.

Required course and distance from Cape Palmas, lat. 4° 24′ N., long. 7° 46′ W., to St. Paul de Loando, lat. 8° 48′ S., long. 13° 8′ E. (Norie).

Ans. S. 58° E. (122°), dist. 1481 miles.

LATITUDE BY MERIDIAN ALTITUDE OF SUN

At sea, merid. alt. ⊙ 38° 15′ 15″ S., I. E., 1° 10′ −; H. of E., 15 ft.; chronom., 4 hrs., 10 min., 18 sec. P.M.; chronom. slow of G. M. T. 4 min., 37 sec.; dec., 4 P.M., 15° 30′ 11″ N., increasing; hourly var., 44.6″. Required lat. of ship.

Ans. 68° 14′ N.

At sea, merid. alt. ⊙ 53° 52′ S.; I. E., −3′ 24″; H. of E., 24 ft.; G. M. T., 4 hrs., 54 min., 10 sec. P.M.; dec., 2° 43′ 12″ N.,

decreasing; hourly var., 57.9″. Required lat. of ship.

Ans. 38° 43′ N.

At sea, merid. alt. ⊙ 48° 18′ 15″ N.; I. E., −2′ 15″; H. of E., 20 ft.; G. M. T., 10 hrs., 26 min., 15 sec. A.M.; dec., 19° 20′ S., decreasing; hourly var., 35.5″. Required lat. of ship.

Ans. 61° 17′ S.

At sea, merid. alt. ⊙ 59° 45′ 45″ N.; I. E., +30′ 15″; H. of E., 15 ft.; G. M. T., 6 hrs., 14 min., 20 sec. A.M.; dec., 4° 09′ 24″ N., increasing; hourly var., 58″.

Ans. 25° 22′ S.

LATITUDE BY MERIDIAN ALTITUDE OF STAR

At sea, Dec. 24, 1894. Merid. alt. * Aldebaran 52° 36′ S.; no I. E.; H. of E., 20 ft.; dec. of * 16° 17′ 52″ N. Required lat. of ship.

Ans. 53° 47¾′ N.

At sea, Dec. 26, 1894. Merid. alt. Sirius 36° 28′ S.; I. E., −45″; H. of E., 14 ft.; dec. of * 16° 34′ 20″ S. Required lat. of ship.

Ans. 37° 3′ N.

LATITUDE BY MERIDIAN ALTITUDE BELOW THE POLE

At sea, April 10, 1885. Merid alt. * Canopus below pole, 22° 38′ S.; dec., 52° 37′ 59″. S.; I. E., +2′; H. of E., 18 ft. Required lat. of ship (Sturdy).

Ans. 59° 55′ 39″ S.

At sea, June 18, 1885. Obs. merid. alt. ⊙ below pole, 8° 10′ 20″; dec. at time of obs., 23° 25′ 57″ N.; I. E., +3′; H. of E., 20 ft. Required lat. of ship (Sturdy).

Ans. 74° 52′ N.

LATITUDE BY EX-MERIDIAN ALTITUDES

At sea, July 12, 1885. Lat. by D. R. 50° N., long. by D. R. 40° W.; obs. ex-merid. alt. ⊙ 61° 48′ 30″; I. E., −3′; dip, 3′ 48″; G. M. T. of obs., 2° 39′ 9″; dec. of ⊙ 21° 54′ 54″ N.; hourly diff. dec., 21.22″, dec. decreasing; equation of time to be subtracted from M. T., 5 min., 20 sec.; hourly diff. equation, .314″, equation decreasing. Required lat. of ship (Sturdy).

Ans. 49° 56′ N.

At sea, June 6, 1880. Lat. by D. R. 49°

21′ N., long. 18° 18′ W.; obs. ex-merid. alt. * Arcturus, 59° 41′ S.; dec. of * 19° 48′ 15″ N.; no I. E.; H. of E., 22 ft.; G. M. T., 9 hrs., 46 min.; G. Sid. T. preceding noon, 5 hrs., 1 min., 6 sec.; R. A. of * 14 hrs., 10 min., 14 sec. Required lat. of ship by ϕ' and ϕ'' sight (Lecky).

Ans. 49° 23¼′ N.

LATITUDE BY THE POLESTAR

At sea, June 21, 1880. Lat. by D. R. 45° 20′ N., long. 37° 57′ W.; obs. alt. of Polaris, 44° 13′ 30″ N.; I. E., + 30″; H. of E., 32 ft.; G. M. T., 11° 45′ 20″; G. Sid. T. preceding noon, 6 hrs., 14 sec. Required lat. of ship (Lecky).

Ans. 45° 17′ N.

LONGITUDE BY CHRONOMETER SIGHT

Observed A.M. alt. ⊙ 20° 30′; chronom. 1 hr., 11 min., 19 sec. P.M.; chronom. 10 min., 20 sec. fast; H. of E., 10 ft.; lat. by D. R. 40° 15′ N.; dec. at noon, 13° 26′ 6″ S.; hourly diff. dec., 50.36″, dec. decreasing; equation of time, 14 min., 27.66 sec.;

hourly diff. equation, .055″, equation decreasing; equation to be added to app. time. Required long. of ship (Patterson).

Ans. 58° 59′ 45″ W.

At sea, Jan. 22, 1895. Obs. alt. of ☉ A.M., 17° 14′; G. M. T., 11 hrs., 42 min. A.M.; H. of E., 20 ft.; no I. E.; lat. 38° 50′ N.; dec. at noon, 23° 33″ S.; hourly diff., 12.48 dec. decreasing; equation of time (to be subtracted from mean time), 3 min., 46.42 sec.; hourly diff. equation, 1.183 sec., equation increasing. Required long. of ship.

Ans. Long. 34° 18′ 30″ W.

At sea, Feb. 27, 1882. Lat. 40° 10′ 45″ N.; H. of E., 30 ft.; no I. E.; obs. alt. * Procyon, 39° 11′ E.; G. M. T., 9 hrs., 58 min., 45 sec.; Sid. T. at G. at preceding noon, 22 hrs., 28 min., 52 sec.; dec. *, 5° 31′ 15″ N.; R. A. *, 7 hrs., 33 min., 10 sec. Required long. of ship, true bearing of star, and Sumner line (Lecky).

Ans. Long. 55° 40′ 15″ W.; true bearing of star, S. 58° E.; Sumner line, N. 32° E.

WAR-TIME PROBLEMS

The problems which present themselves to the navigator in war-time, particularly when he is near a coast, are of especial difficulty and demand extreme caution in their treatment. Modern warfare, which has brought with it the extensive employment of the submarine and the equally extensive use of submarine-chasers of various types, patrol boats, mine-sweepers, and other craft, has set up conditions of inshore navigation quite unknown to the earlier naval officers.

Since it must be obviously the policy of the United States Government to meet the new conditions by the building and manning of an enormous fleet of coast-patrol vessels of the numerous kinds, to be kept in use not only in the present war, but as long as the submarine menace exists to threaten vessels threading the narrow seas or approaching the coasts of the great ones, it becomes imperative that the officers handling the patrol craft shall make themselves past-masters of the comparatively new problems in navigation.

In the first place the commander of a patrol vessel must realize the indisputable fact that a submarine can secretly enter an unfrequented bay and lie concealed in some small bight or inlet, provided there is water enough to float her. She can also lie on the bottom for a long time. That submarines will do either has proved to be the case over and over again in British waters, and it is likely to be the case here, especially since no country is wholly free from disloyal persons who would gladly communicate with submarines in order to give them information or stores.

Again, the patrol vessel will at times be glad of her own ability to find concealment in some such unfrequented inlet or bay. One of the first duties, then, of a patrol commander is to make himself absolute master of the details of the coast which he patrols. All the information which he needs will not be found on the charts. There are a thousand tricks of the local tides, for example, which only the local man knows. For instance, in the East River immediately behind Bellevue Hospital the flood tide sets in toward the pier-head instead of up the river. Tugboat captains all know a thing like that. Strangers do not. In a hundred other details of such kind all coastwise navigation carried on close

inshore or among islands abounds, and the stranger can easily get into trouble through ignorance of them.

Local fishermen are prolific sources of information in regard to such matters. It is a part of their business to know them. The patrol-boat commander should draw as much of such information as he can get from the fishermen who, once they understand the object of it, will give it readily and intelligently. Another invaluable set of men from whom to acquire this kind of knowledge is skippers of racing-yachts of the locality.

Having gathered every possible scrap of information of this kind, the patrol-boat commander should next turn his attention to all kinds of landmarks which can be used in establishing a position when in sight of land. Here the fishermen will prove invaluable, for it has been the observation of the author that these men are in the habit of utilizing church spires, water-towers, etc., in giving them bearings by which to reach points desired. The navigator will not find these things on his chart, but he can put them there, and that is what I advise him to do. Also it is a good plan to make a record in some convenient place of the exact location of such things as railway stations, telegraph and post offices,

coal-yards, life-saving stations, and shore hospitals wherever they exist.

ABSENCE OF LIGHTS AND BEACONS

The navigator must not forget that in wartime he may be deprived of most of his familiar lights and beacons. War-time often means lights out. The navigator has to transform himself into a marine cat, with eyes that can see in the dark. Fortunately the less artificial light there is in the neighborhood the better a man can see at night.

But in alongshore work his sight will be of little value to him if he does not know the sky-line of the coast. This is a thing which every coast-patrol officer should study assiduously. The occasions on which knowledge of it will become important, even vital, are innumerable. A fisherman of Block Island, for example, does not need the light on the south end of the island to assure him that he is not running in for Montauk Point. The loom of the almost indistinguishable land in the blackness of the night will tell him what he needs to know and he will steer with confidence.

A patrol officer working along the New Jersey shore should be able to tell from the

shoulder of the Highlands precisely how to steer to get the Ambrose Channel buoy or the one off the point of the Hook. And he should be so certain of that shoulder that he could take a departure from it in the middle of the night and steer boldly for, let us say, the entrance to Block Island Sound. How accurately such things can be done may be illustrated from an actual case.

Steaming west (in squadron) along the south shore of Long Island on a naval-militia cruise the naval officer on watch on the leading ship was anxious to check up his course by a bearing of Shinnecock Light, then miles distant. He could not find the light, nor could the lookout at the masthead. The naval-militia officer on watch was an experienced small-yacht cruiser and knew the waters intimately. He asserted that he recognized the sky-line of the land and was certain that the ship was abreast of a certain village. He went to the chart, laid off the bearing of Shinnecock Light from the calculated position of the ship, and with the glasses found the pin-point of light precisely where he believed it should be found.

This instance serves to show how important a knowledge of the land is to the officer navigating.

LINES OF BEARING

Particular attention may be called here to the usefulness of lines of bearing in alongshore work. This matter has already been treated at page 154 *et seq*. The point just now is that a small coast-patrol vessel will rarely change her latitude so much that a new latitude observation will be required. If you are anywhere within forty miles of the Ambrose Channel lightship you may assume her latitude to be yours.

Now you can find on any clear night at least one conveniently located star which will give you a good line of bearing. And you have only one chronometer sight to work out. Your azimuth gives you the required line of bearing, running at right angles to the true bearing of the observed star. The sun may not always be as conveniently located as the stars, but there is rarely a time when it cannot be advantageously used to acquire *some* information.

At any rate, in the department of navigation by observation there is no other method than the Sumner with a single line which gives useful results so quickly and easily. The coastwise navigator should, therefore, make himself master of taking azimuths and

get this method at his fingers' ends. An admirable paragraph in Sturdy's *Practical Aid to the Navigator* is pertinent here:

"After having been for some time without an observation and any body sufficiently high in altitude shows itself, take its altitude and bearing and note the time. The observation will be good for something—it will give you either latitude, longitude, or a line of position, any one of which will put you on a line, and show the relative bearing of any land that may be near."

COMPASS AND LEAD-LINE

Perhaps one or two special remarks about the compass and lead-line in the more or less blind navigation of war-time along a coast may not be amiss. In the first place, officers must impress on the minds of all members of the crew that they must not go near the compasses with any steel on their persons. I have seen a ship's standard compass thrown out 3 degrees by the mere act of a naval-militiaman peering into the binnacle while he had a steel gromet in his cap. A knife in the pocket may do quite as much or more. I have seen a regular seaman carefully deposit a six-inch shell at the foot of the standard

compass binnacle with results quite puzzling to the navigating officer till he made a personal examination.

Furthermore, the commanding officer of a vessel should see to it that his compass is stationed in the best possible place. The builders do not always take care to do so. In every steel or iron ship there is a neutral spot where deviations are reduced to the minimum. Naturally this spot is most frequently one where a compass cannot be put; but it is worth while to look for it. You may be able to use it.

Do not allow the compass to be placed where shifting steel or iron, such as the topping-lift of a boom or the bolt in the heel of a derrick, is near it. Every change of position in such shifting metal will alter the deviation of the compass. And it will not make any difference what stands between it and the compass. Magnetism will operate through anything, even a stone wall.

If your compass has compensating magnets see that they are inside the binnacle box and that you have it locked and the key in your pocket. Ignorant members of the crew sometimes find the binnacle box a handy place to stow a pair of scissors or a knife. The result is compass error. Magnets fastened to the

deck outside the binnacle box are likely to be moved by some one unacquainted with their importance. In the kind of navigation to be done alongshore in war-time, and especially in the frequent fogs of our summer, or at night, the compass will be the officer's mainstay. He must needs see that it is well guarded. Next to that will come the lead. Of course the type of craft designed for patrol work, especially the submarine-chasers, draw very little water and will seldom be in danger of grounding except when very close inshore or in waters dotted with "middle grounds" and other traps.

But the use of the lead in ascertaining the position of the ship will be frequent and invaluable. This matter has already been fully treated (pp. 32, 47). But the coast-patrol officer should study his chart till it becomes an integral part of his information. He should be able to get some information from a single cast and more from a series, even on the thickest night. In short, he should aim at resembling the New England skipper who was so intimately acquainted with the bottom that his men tried to play a practical joke on him by salting the lead one night with a bit of earth brought from the home port. Whereupon he exclaimed;

"Stop the ship! We're right over old Marm Hackett's garden."

Soundings on the Atlantic coast of the United States are of a nature to be extremely useful in coastwise navigation. A patrol boat engaged in the swift and arduous business of submarine-chasing may often run out of her reckoning and lack opportunity to obtain a good fix by observation. But she will almost invariably be able to locate herself by soundings.

Of course small patrol boats will not be equipped with deep-sea sounding-machines. The hand lead will have to serve them and when they are in more than twenty fathoms they will have to find their position either by observation or by running in with the land till within twenty fathoms.

SIGNALING AND QUARTERMASTERS

In any vessel large enough to rate a navigating officer the whole business of signaling belongs to his department. The navigator's division includes the ship-control crew, the signal crew, and the radio crew. The navigator's principal non-commissioned assistant is the chief quartermaster, who should have a sufficient knowledge of elementary navigation

to equip him for his post. He must also be fully acquainted with all the Navy methods of signaling, by the code flags, the international code flags, the Ardois lights, flashlights, and wigwag.

A coast-patrol boat will, of course, not rate a navigating officer nor a chief quartermaster. The duties of these positions will fall upon the commanding officer and such petty officer (quartermaster) as the department allows him. In fact in small craft handled by small crews handy men will have to be in the majority, and it will generally be a case of "all hands and the cook" in every watch.

Officers of patrol boats, coast-guard boats, etc., should be their own chief quartermasters and should have signaling at their fingers' ends. The systems will be found concisely explained in the *Deck and Boat Book* of the Navy, which can be obtained from the United States Naval Institute at Annapolis. They are also to be found in the *Blue Jacket's Manual*, likewise published by this institution. Every seaman on a war-ship is now required to know how to send and receive wigwag. This rule should, of course, apply to officers and men on patrol craft.

It need hardly be added that every officer

and quartermaster should be thoroughly acquainted with all foreign flags and uniforms.

MINE-FIELDS

In war-time harbors are mined and a small channel is left for the passage of vessels. It is the duty of every officer to acquaint himself with the location of all mine-fields. Patrol-boat officers should have records of those in their districts and should indicate their boundaries on their charts.

It is customary to detail a vessel to serve as a mine-field guard and directions given by such vessels should be scrupulously obeyed.

Similar rules apply to harbor entrances protected by steel nets. There is a passageway through every such net, and this will be indicated to properly authorized craft by the guard vessel on duty at this point. No boat should attempt to pass a mine-field or a net at any point except that indicated.

Merchant-vessels of neutral nations are usually permitted to enter mined harbors at stated hours and to depart likewise at fixed times. In such cases they are customarily guided by the patrol boat on duty.

THE NAVAL COAST-DEFENSE RESERVE

This is the branch of the Naval Reserve force especially needed for the patrol of our coasts to detect raiders, submarines, and other craft. It includes patrol boats, seamen and officers for them, civil, structural, and mechanical engineers, and all others who can be utilized. Lieut. R. F. Barnard, U.S.N., has prepared a pamphlet giving information on this subject. It can be obtained at the office of the Naval Training Association of the United States, 26 Cortlandt Street, New York, or 42 Water Street, Boston.

The plan calls for seven hundred and fifty boats and ten thousand men to patrol the third district alone, comprising the waters from Barnegat, New Jersey, to New London. Small motor-boats to operate close to shore, larger ones to work farther out, and coast-guard vessels, tugs, large yachts, etc., to be on the outer line as scouts and to act as convoys for merchant-vessels are to be used. The pamphlet says:

"A patrol-boat unit, as we call it, for small

boats, say, forty feet, would be one ensign, one quartermaster, one engineer, and four seamen. Two members of that unit must be experienced to some extent; they are the ensign and the engineer. Unless you have an engineer who can handle your engines properly you might just as well anchor your patrol boat and stay there. The ensign has got to be familiar with coastwise navigation, know how to read charts, how to fix cross bearings, etc. He should not have gotten his knowledge out of books entirely, but by kicking around on boats; in other words, he should be a yachtsman, a good fisherman, or something like that, but so far as the other men in that unit are concerned, they need have had no previous experience. If we only enrolled as quartermasters in this Naval Reserve men who know how to signal, we would have very few quartermasters. We take them on faith, hoping they will learn and learn quickly.

"The same thing applies in regard to seamen. The first thing that we want them to study is ordnance, especially the small guns, such as one-pounders, three-pounders, six-pounders, and machine-guns. Then after that we will want the seamen also to learn signaling. The ensign has got a whole lot to learn. He ought to know something about

naval regulations; something about limits of submarines; something about scouting; something about mines and mine-sweeping; and should inform himself as to deep-sea navigation, if practicable. Any member of these units has got enough work to last him for a long time, but you have got to have instruction, some from studying, and some from experience, and the best way to get this practical experience is to enroll in this Reserve and let us direct your course of study."

One of the attractive features of this service is that it permits a yachtsman to organize his own crew from among his friends and enroll together. This service should appeal with great force to yachting-men, power-boat owners, and former naval-militiamen. There is plenty to do and the need of men and boats will always be great. When there is no war, a man can resign if he wishes to, or remain subject to call.

THE END